TFAWS 2015

Thermal Coatings Seminar Series Training
Part 2 : Environmental Effects

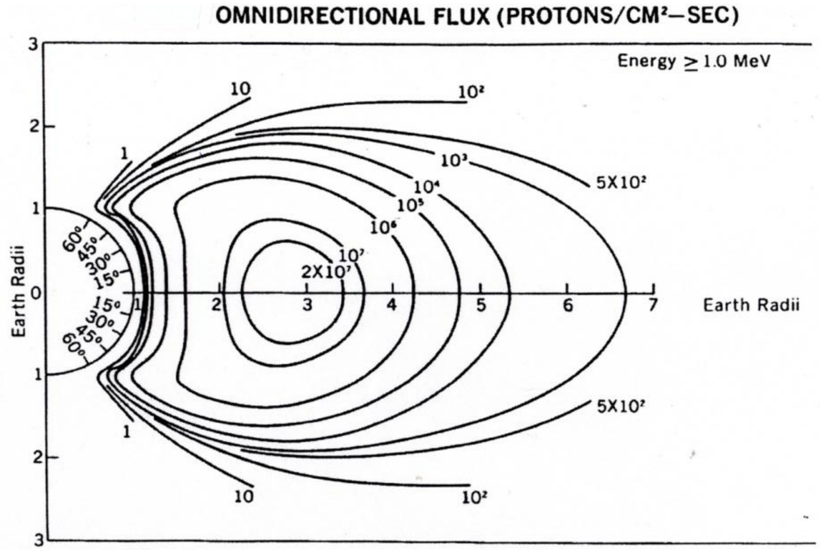
NASA GSFC Contamination and Coatings Branch – Code 546

Hosted by: Jack Triolo - SGT, Inc.

Agenda

- Orbital Environments versus Orbital Altitude
- Tests for Environmental Effects on Coatings
- Orbital In-flight Test Descriptions
- Orbital In-flight Test Results versus Orbital Altitude
- In-flight Results versus Laboratory Test Results
- Atomic Oxygen In-flight Tests and Results
- Returned Flight Hardware
- Coating Issues

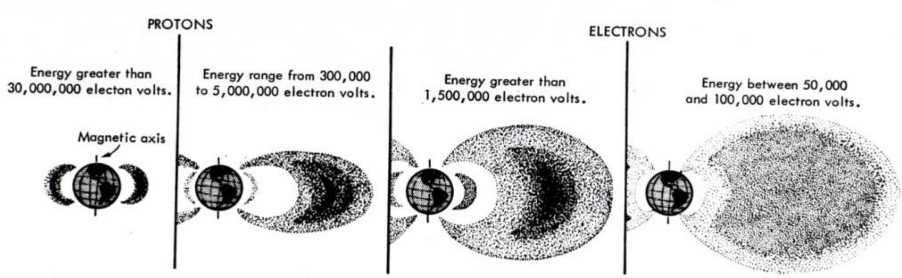
CHARGED PARTICLE ENVIRONMENTS



Plot of Constant Intensity Flux Contours with an Energy of ≥ 1.0 MeV

Earth Radius=6,300 km (4,000 mi)

THE VAN ALLEN BELTS SEEN IN CROSS SECTION IN TERMS OF FOUR TYPES OF PARTICLES



Van Allen radiation belts, as detected by rocket and satellite shots. Because the earth's magnetism weakens with distance, the most energetic protons (left) are trapped nearest the earth. Low-energy electrons (right) are evenly distributed over *magnetosphere*. (*Adapted from the New York Times, April 11, 1962.*)

Induced Environments

- All Orbits
  - Direct view of contamination source to sensitive surface combined with UV, CP, AO.
- LEO
  - Ambient return flux in ram (velocity) direction. Outgassing molecules colliding with ambient atmosphere and returning to spacecraft surface.
- MEO/GEO
  - Electrostatic Return (ESR). Molecule ionized by UV and attracted back to charged s/c surface
- Space Debris
  - Anything from paint flacks to nuts, bolts, and tools.

Orbital Altitudes

- LEO -- <1000km ---- UV, AO, Low Flux Charged Particles (CP)
- GEO -- 35,786km ---- UV, High Flux CP
- MEO -- >1000km to 25,000km ---- UB, Very High Flux CP
- L1, L2, Lunar ---- UV, Solar Wind (Low Energy Protons + Electrons)
- Elliptical ---- All of the above but lower fluxes

How do we Test for Environmental Effects?

- Laboratory Testing (measured in-situ or ex-situ)

  - Vacuum UV (1216 Å to 1800 Å)
  - UV (1800 Å to 4000 Å)

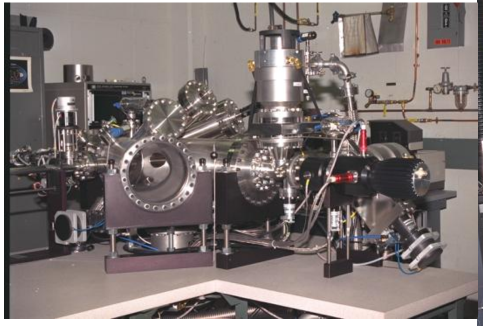
  - Charged Particles – electrons and protons tested to adsorbed energy – Rads (material specific) with mono energetic electrons and protons, which can be combined or separate and with or without UV

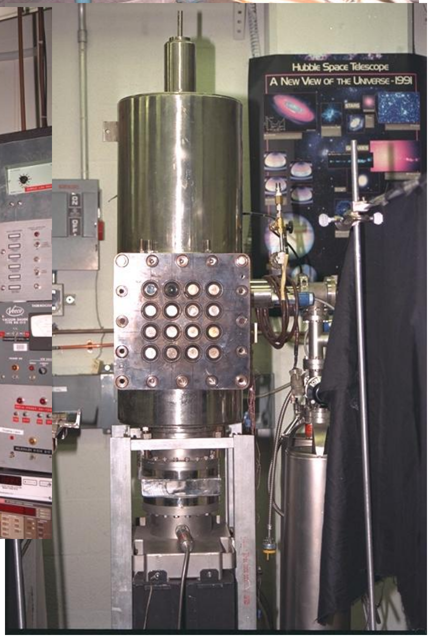
  - Atomic Oxygen – with or without UV

  - All of the above + intentionally introduced molecular contaminates

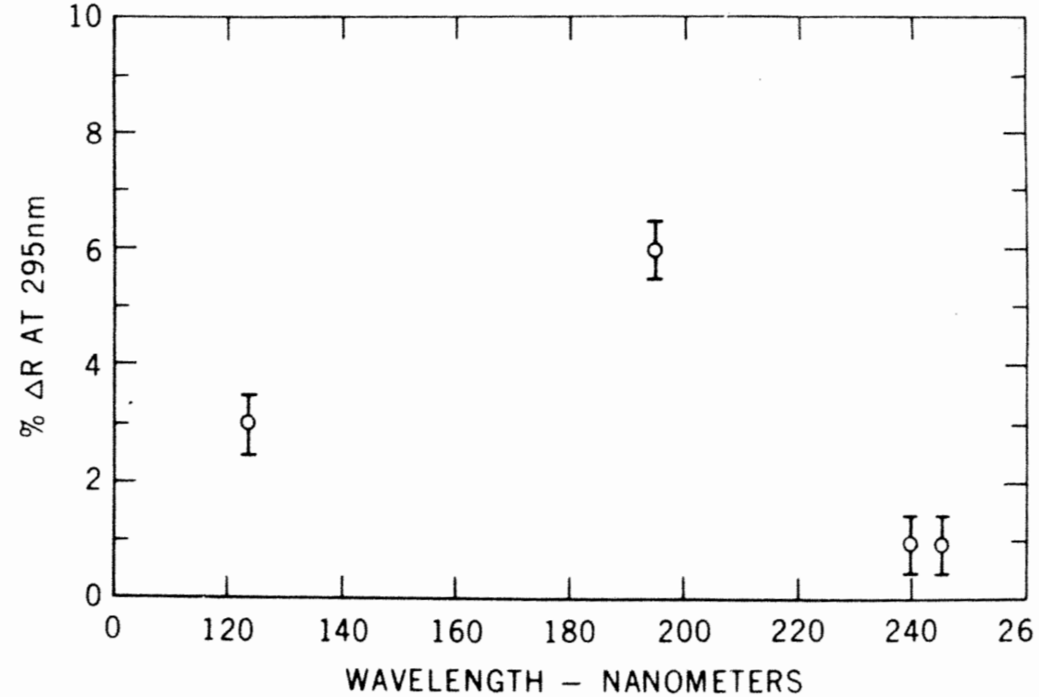
NASA-GSFC Coatings Space Environmental Test Facilities

- Calorimetric Emittance Facility
- Multisedes “UV” Degradation Chamber
- Solar Wind Facility
- Electrostatic Charge Facility
- Thermal Cycling Chambers
- Various Vacuum Chambers





ALZAK UV DATA



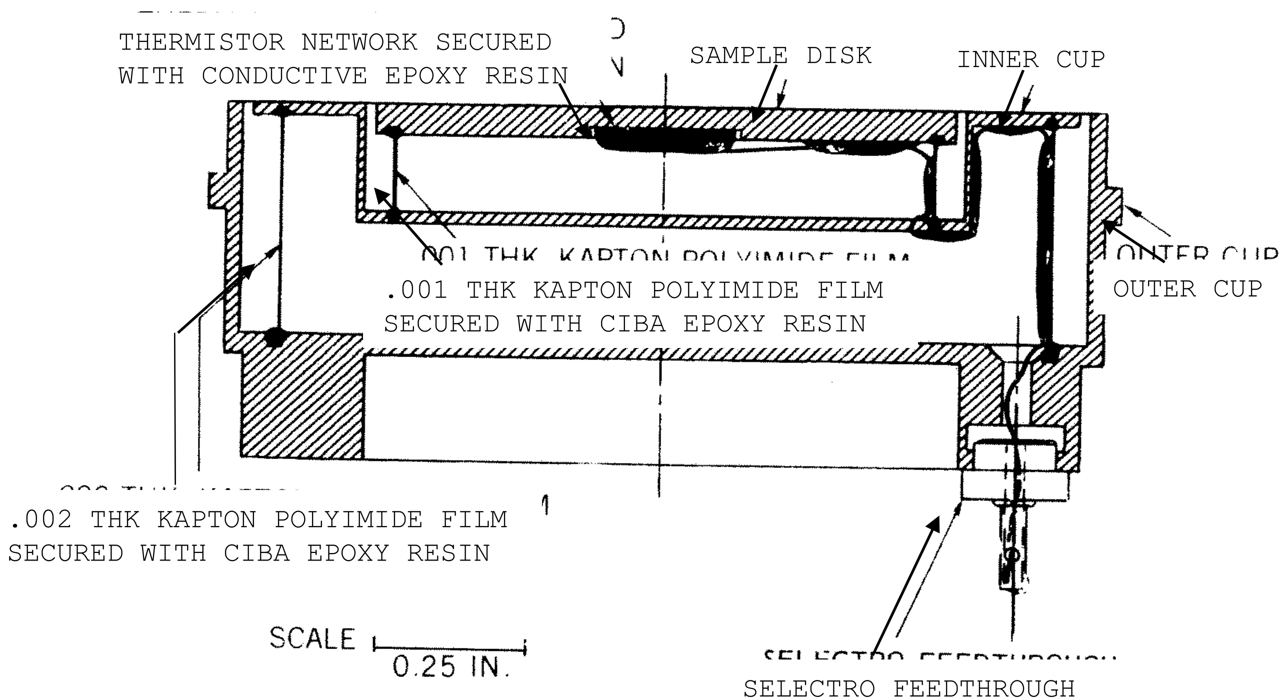
Irradiation Damage of Alzak as a Function of Wavelength for Constant Incident Energy

Damage varies with wavelength and material

On-Orbit In-Flight Testing

- LEO
  - OSO-8
- GEO
  - ATS-1, ATS-2, ATS-3, SCATHA (P87-2)
- MEO
  - NTS-2
- 35 Earth Radii
  - IMP-8
- CMP
  - LDEF, STS-8 (GAS-CMP), STS-11 (GAS-CMP), EOIM-3

COATINGS CALORIMETER



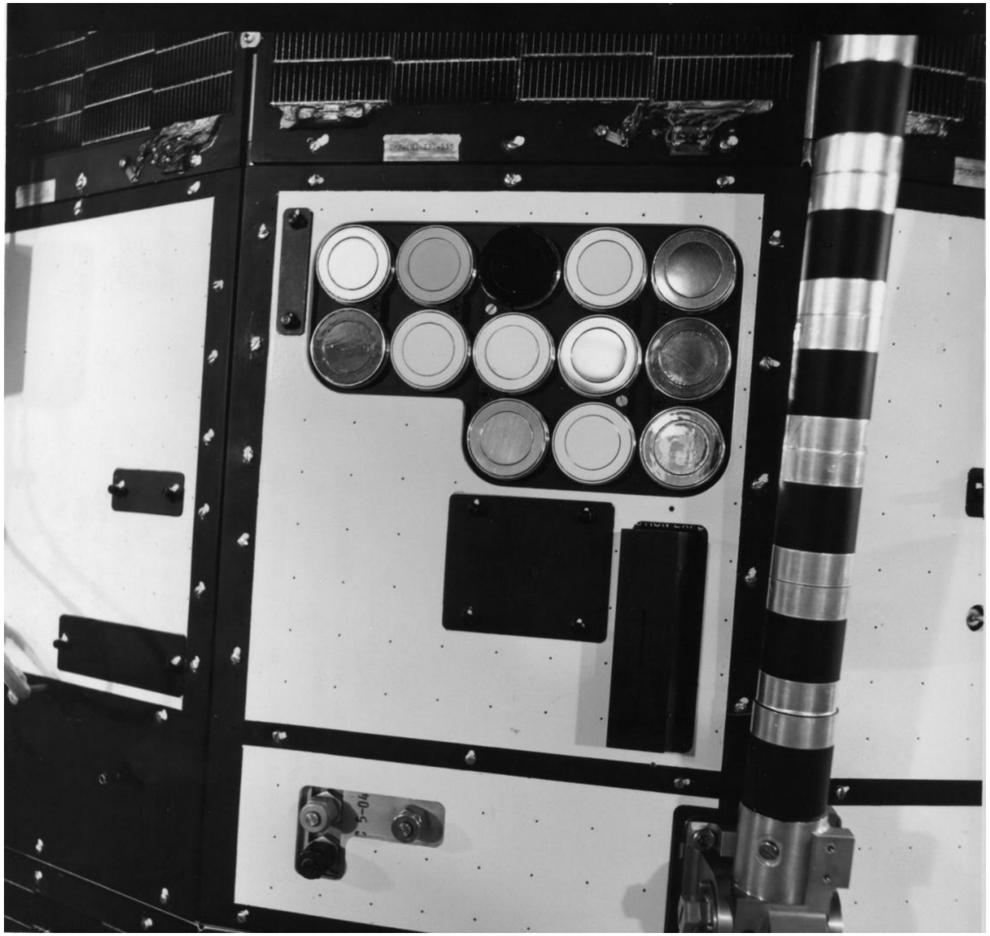
Sensor Cup Design

Calorimeter design with inner cup and sample disk having the same area

AST-2

ATS-2 Coatings
Experiment
GEO orbit

OSO-8



OSO-8 Coatings
Experiment intergraded
into the S/C

OSO-8

OSO-8 Coatings
Experiment
LEO orbit

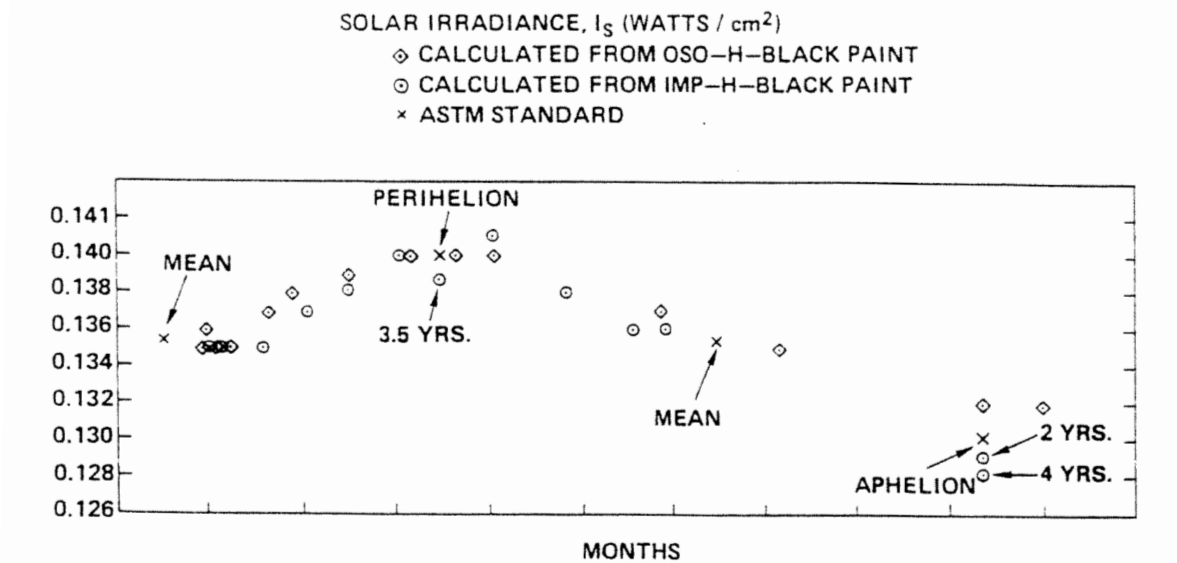
Comparison of Flight Data for Various Orbits

COATING	LEO (OSO-8) 348X203 miles	MEO (NTS-2) 10,000 miles	GEO (ATS-1 & SCATHA)	EX-GEO (IMP-8) 136,000 miles
	Delta a/3yrs	Delta a /month	Delta a /3yrs	Delta a /3yrs
AL/SiOx	0.0		0.10	0.05
CC/AL	0.0	0.02 /month	0.05	0.03
MS-74	0.0		0.34	0.13
Ag FEP	0.01	0.012 /month	0.08	0.06
Al FEP	0.02			0.04
NS43C/G		0.023 /month	0.09	
OSR		0.01 /month	0.02 (0.04/10yrs)	
Kapton			0.10	0.14

MEO has the highest degradation rate

LEO has the lowest degradation rate

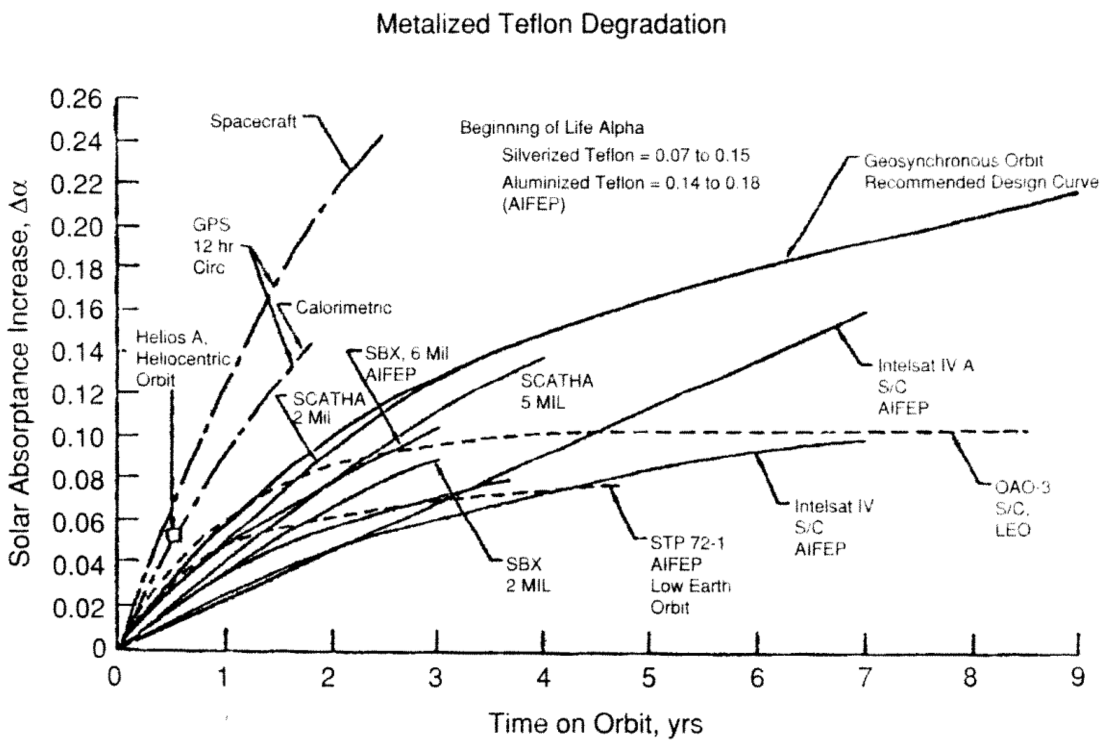
COATINGS EXPERIMENT BLACK MONITOR



Monthly Variations of Solar Intensity calculated from IMP–H and OSO–H black paint data.

Black paint shows effect of bleaching with UV exposure

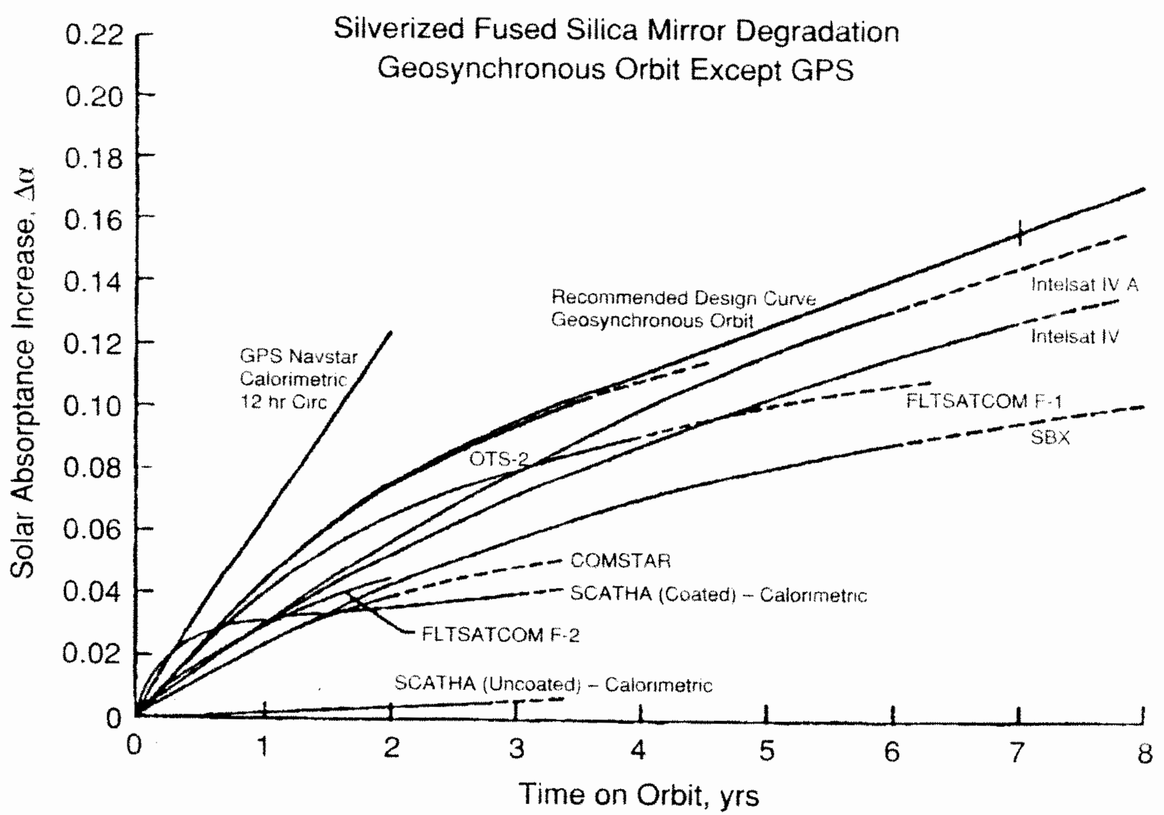
TEFLON FLIGHT DATA



Metalized Teflon degradation (in geosynchronous orbit unless otherwise indicated)

Solar absorptance changes orbit and s/c cleanliness dependence

OSR FLIGHT DATA

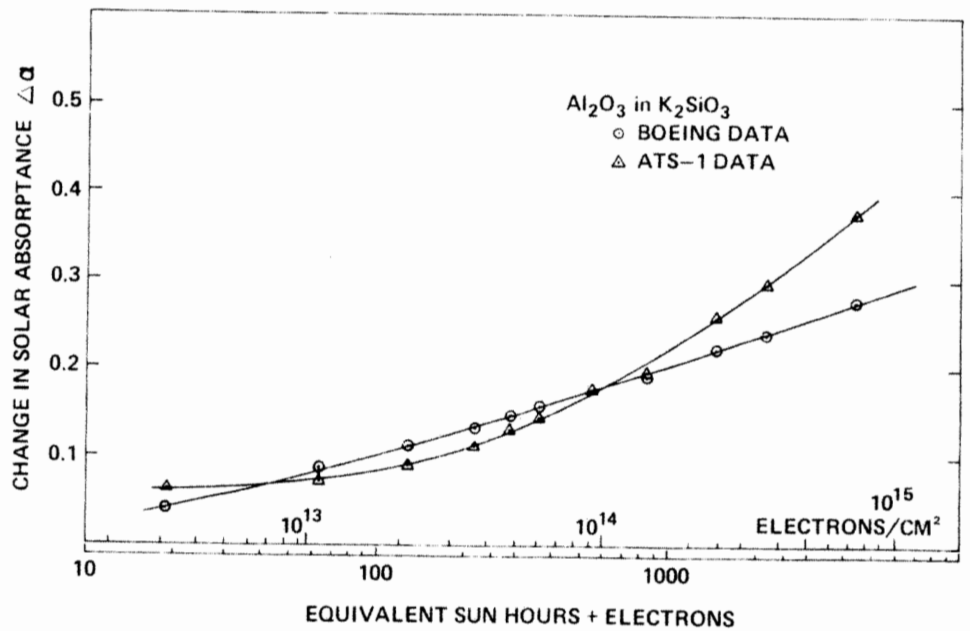


Degradation of quartz mirrors in geosynchronous orbit

Same orbital and s/c cleanliness dependence

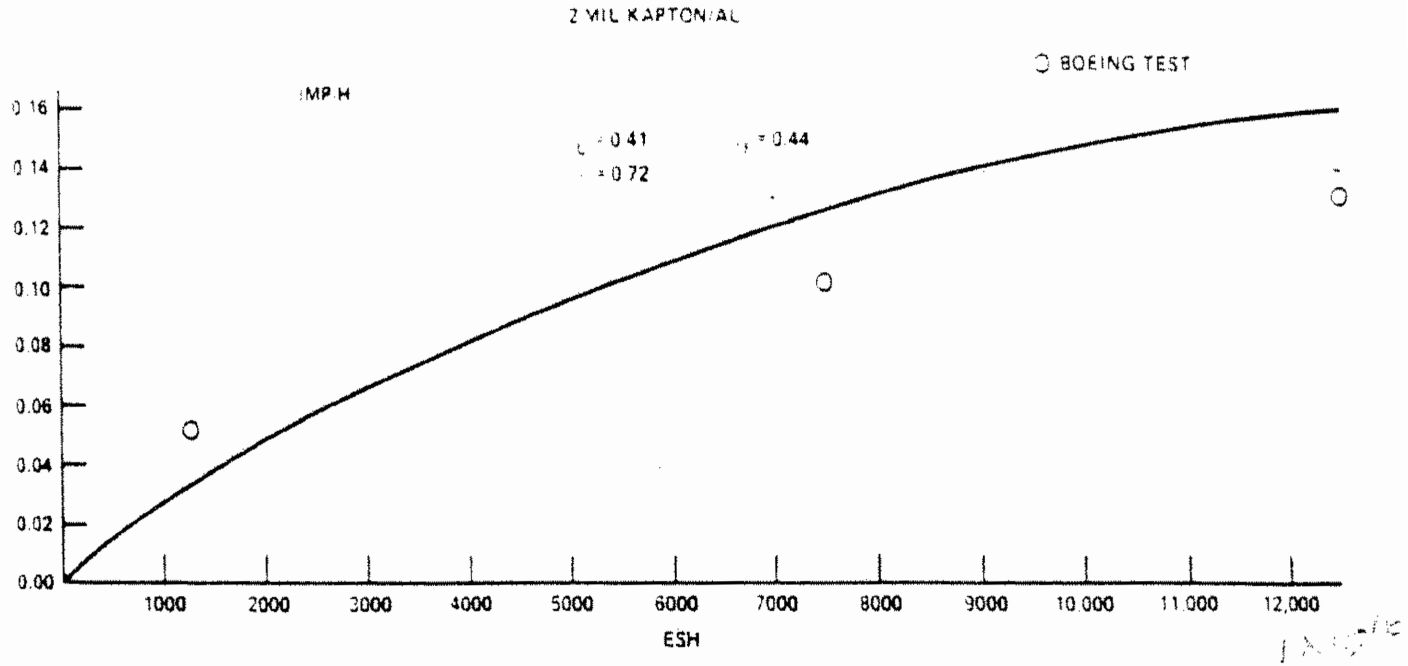
Comparisons Between In-Flight and Laboratory Testing

ATS-1 / LABORATORY COMPARISION



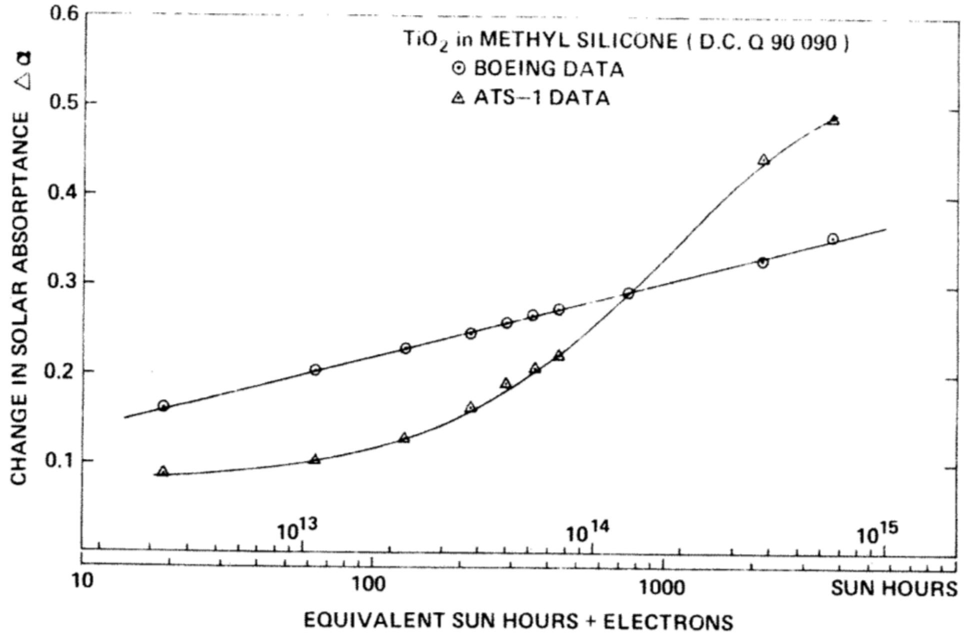
$\Delta\alpha$ as a Function of Solar and Electron Irradiation and Comparison With ATS-1 Data for Al_2O_3/K_2SiO_3

IMP-8 / LABORATORY COMPARISON



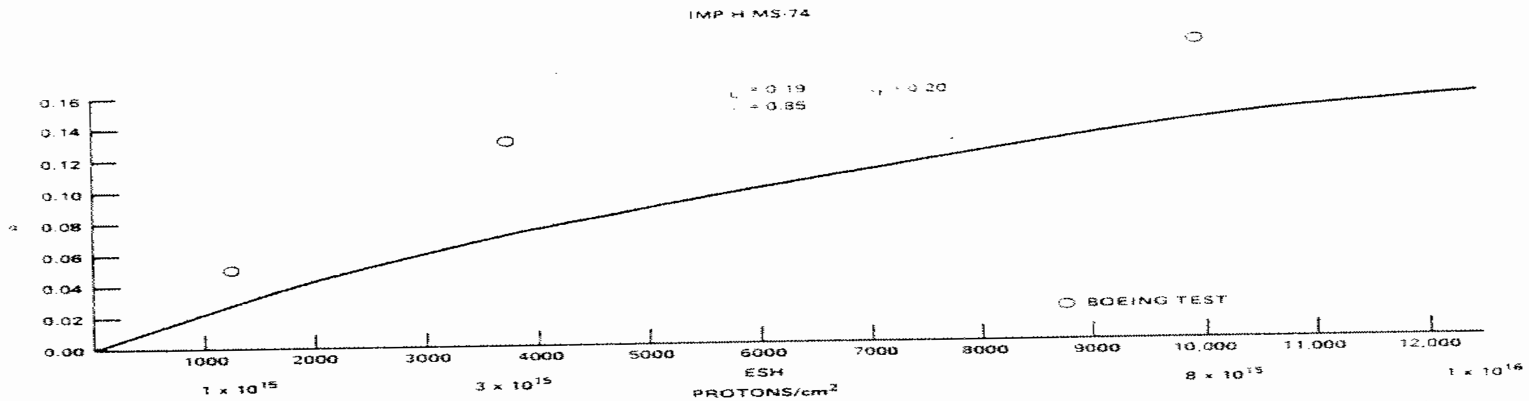
Δα of 2 mil Kapton/Al as a function of Orbital exposure—from IMP-H, compared with Boeing laboratory test data.

ATS-1 / LABORATORY COMPARISION

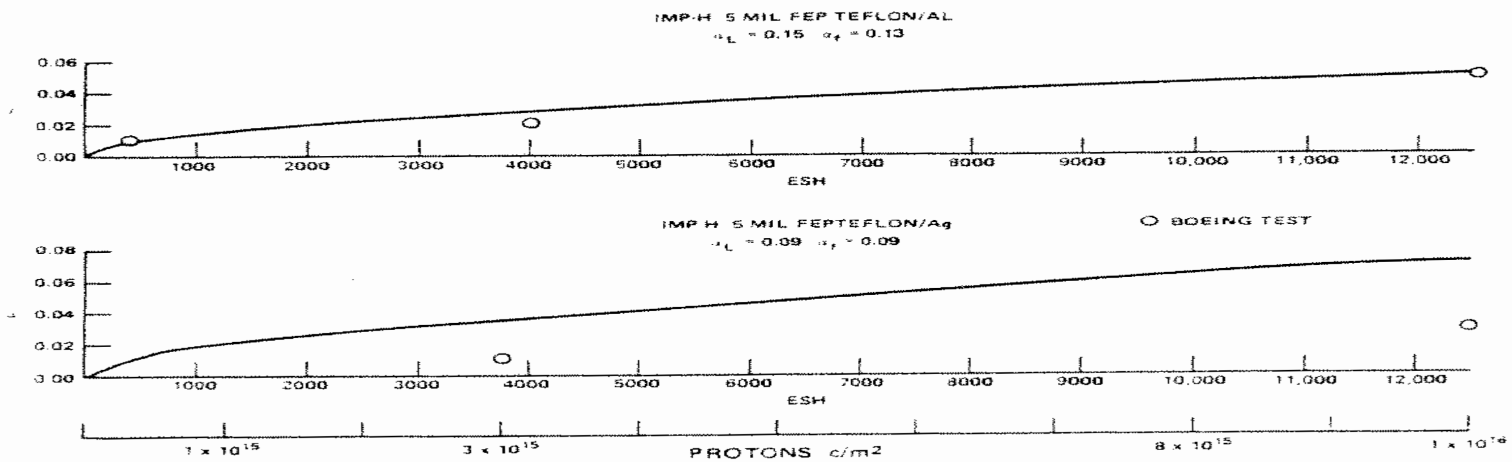


$\Delta\alpha$ as a Function of Solar and Electron Irradiation and Comparison With ATS-1 Data for Dow Corning Q90-090

IMP-8 / LABORATORY COMPARISON

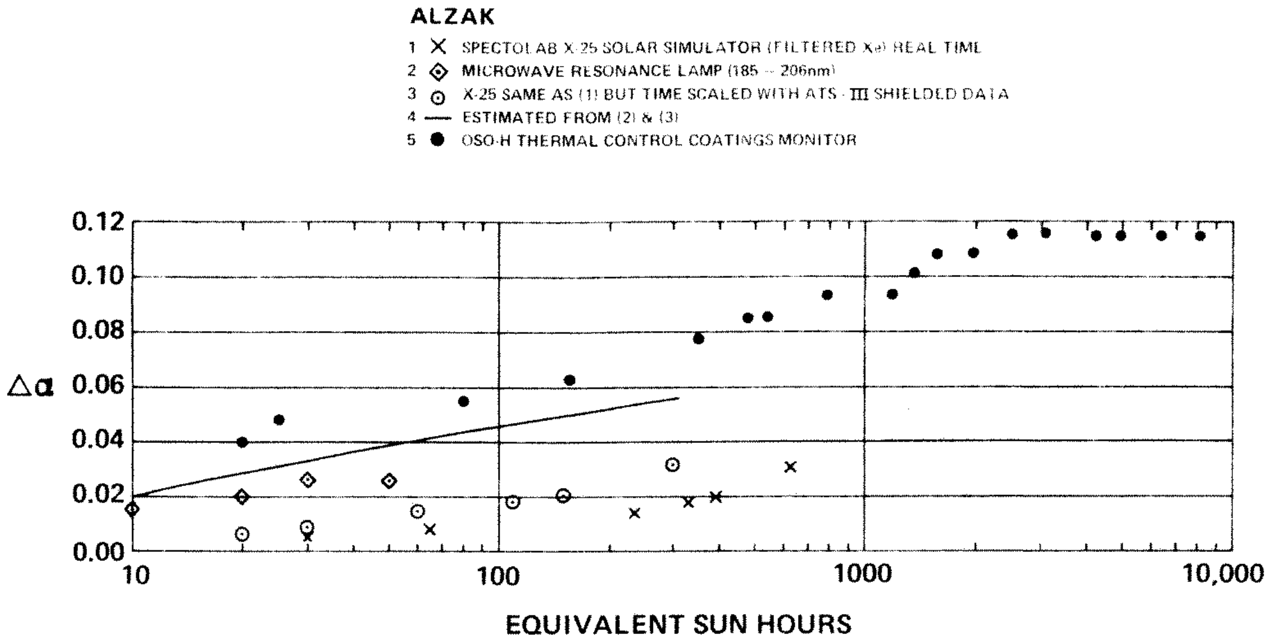


Δα of MS-74 white paint as a function of orbital exposure—from IMP-H, compared with Boeing laboratory test data.



Δα of FEP Telfon, coated on the back surface with evaporated Al or Ag, as a function of orbital exposure—from IMP-H.

FLIGHT VERSES LABORATORY



Δa of Alzak "Control" – Comparison of Laboratory and In-flight Test Data

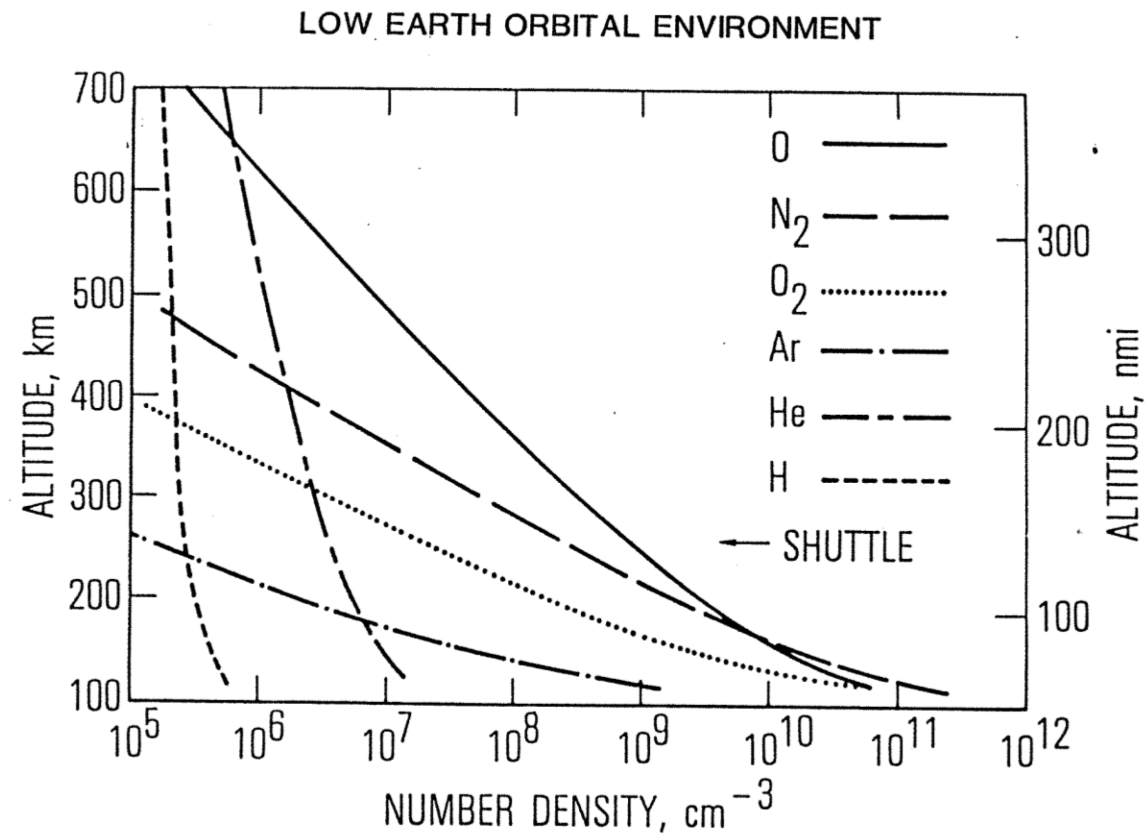
Atomic Oxygen Effects

- What affects AO flux?
  - Altitude
  - Solar Cycle
  - Ram Direction

- In-Flight Results

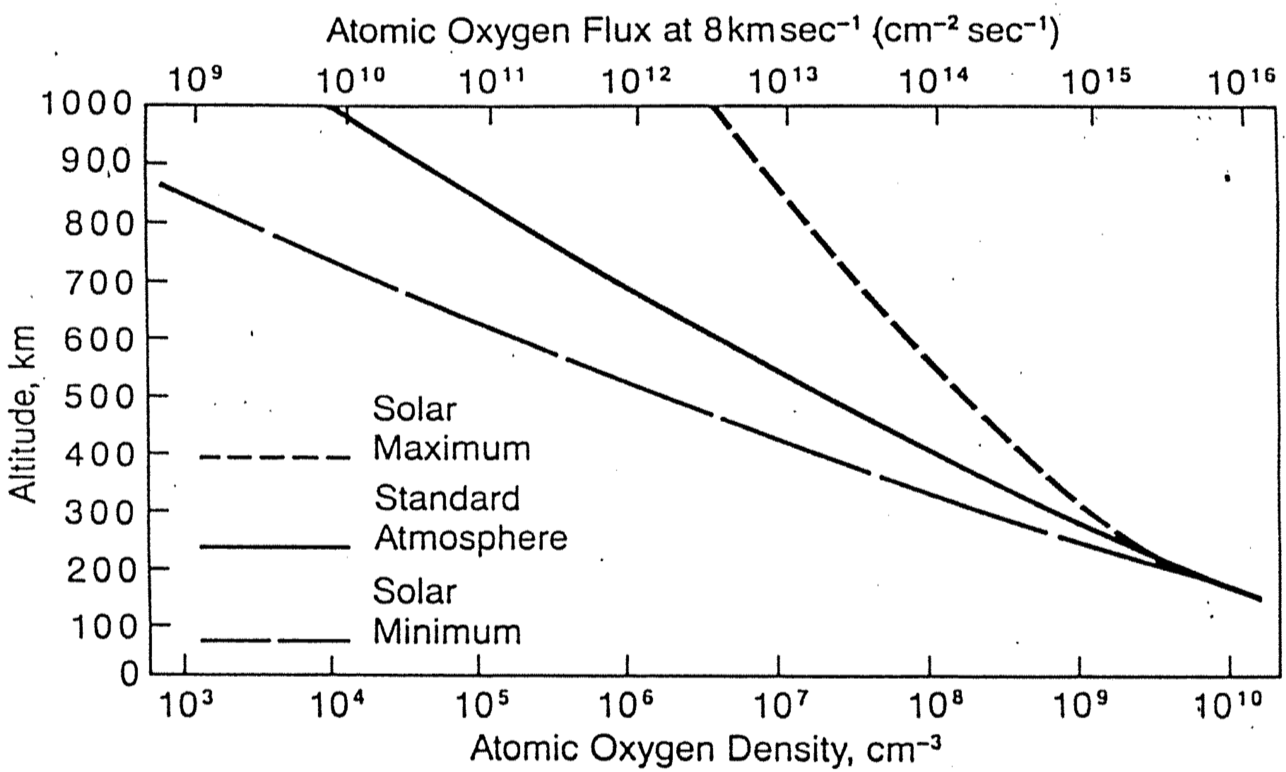
- Reaction Rates for Various Materials

ATOMIC OXYGEN



TEXT

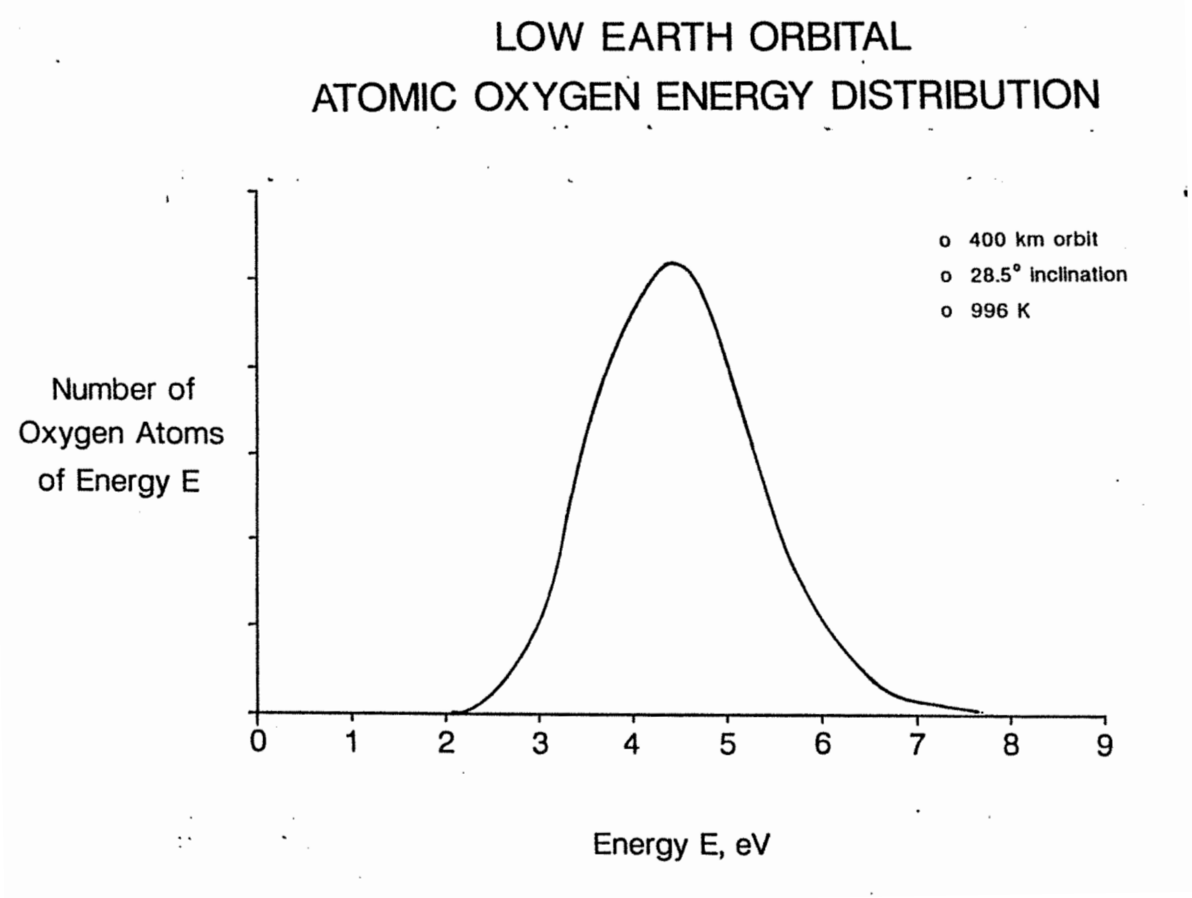
ATOMIC OXYGEN



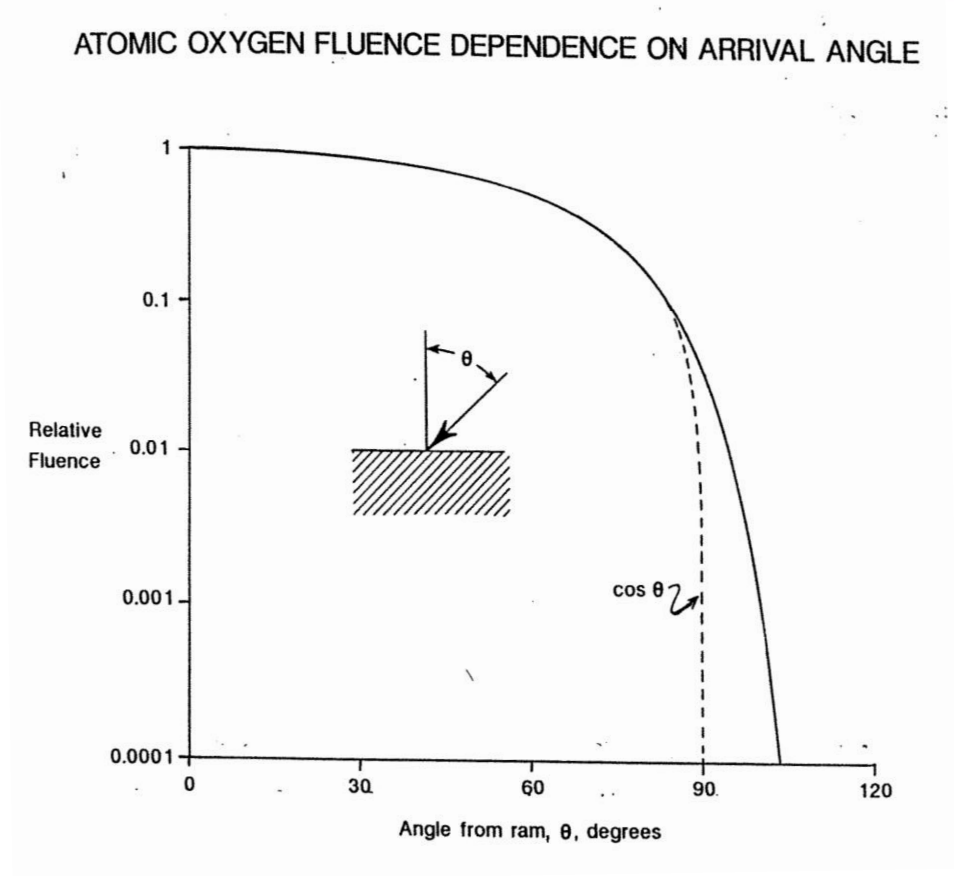
Atmospheric atomic oxygen density and flux in low Earth orbit.

Large range of flux between solar max and min

ATOMIC OXYGEN



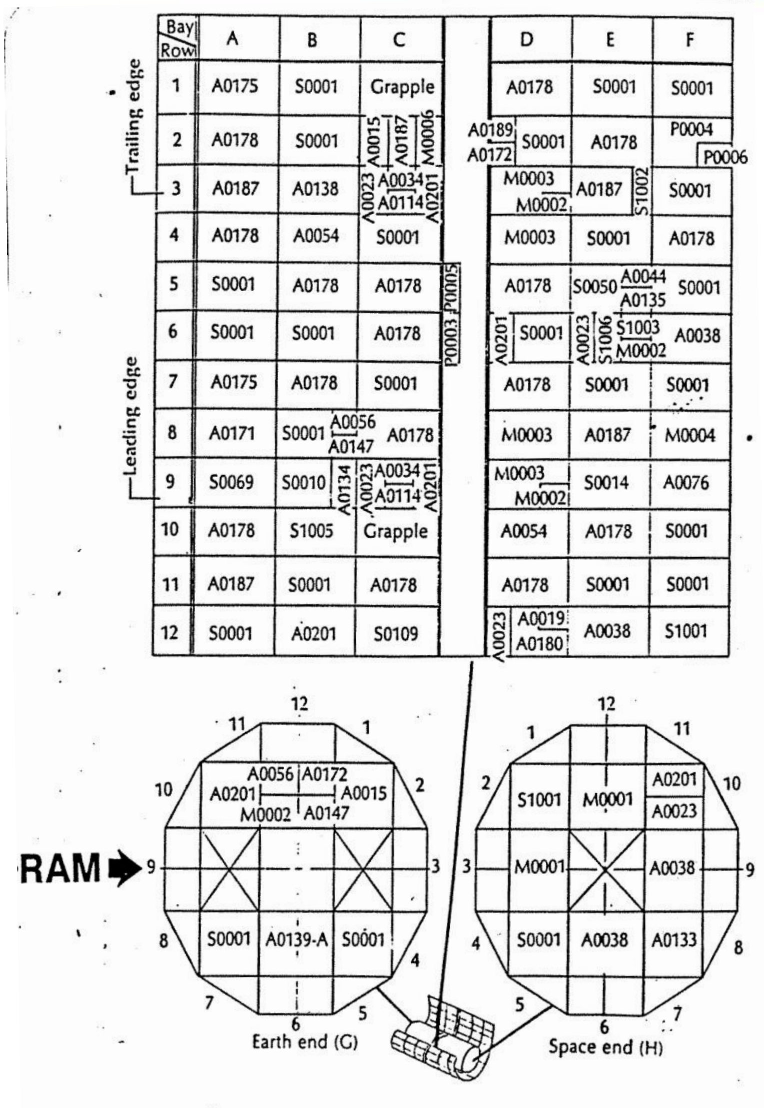
ATOMIC OXYGEN



Slight spread effects past 90 degrees

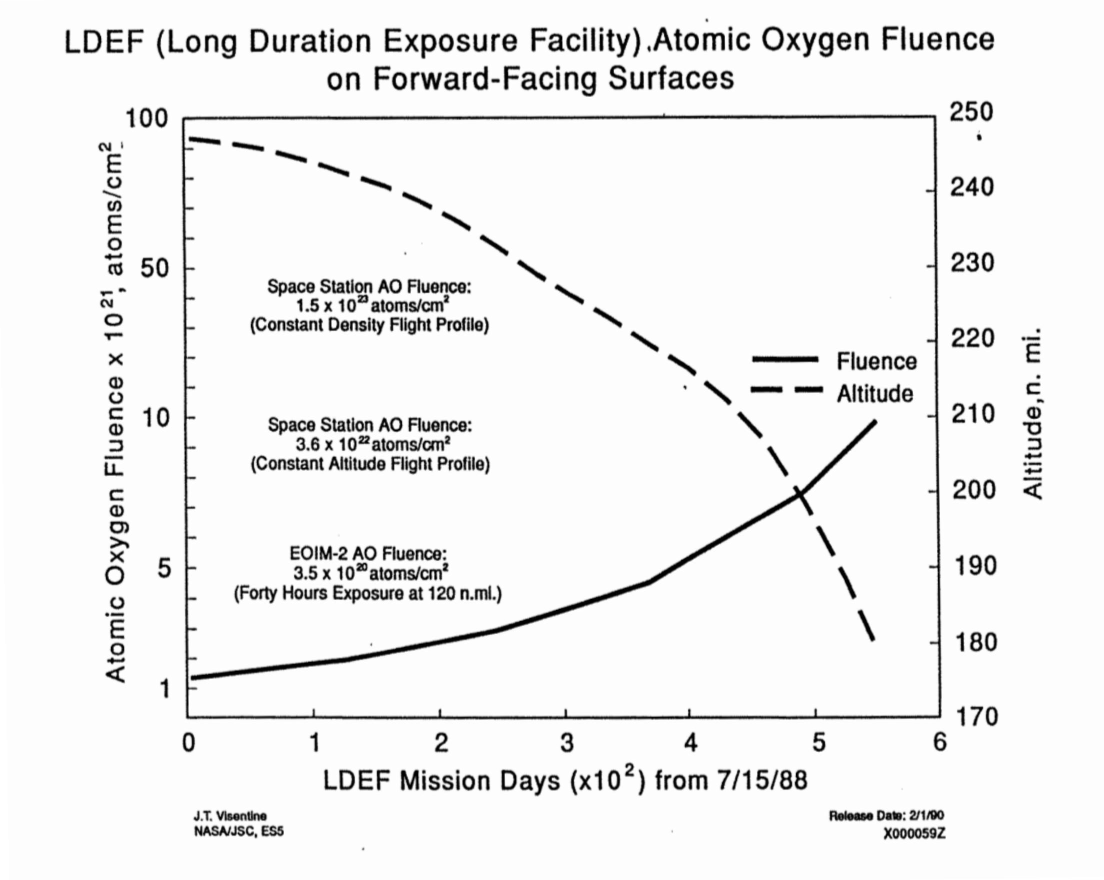
On-Orbit In-Flight Testing

- LEO - OSO-8
- GEO - ATS-1, ATS-2, ATS-3, SCATHA (P87-2)
- MEO - NTS-2
- 35 Earth Radii - IMP-8
- EMP
  - LDEF (Long Duration Exposure Facility), STS-8 (GAS-CMP), STS-11 (GAS-CMP), STS-13-EOIM 3



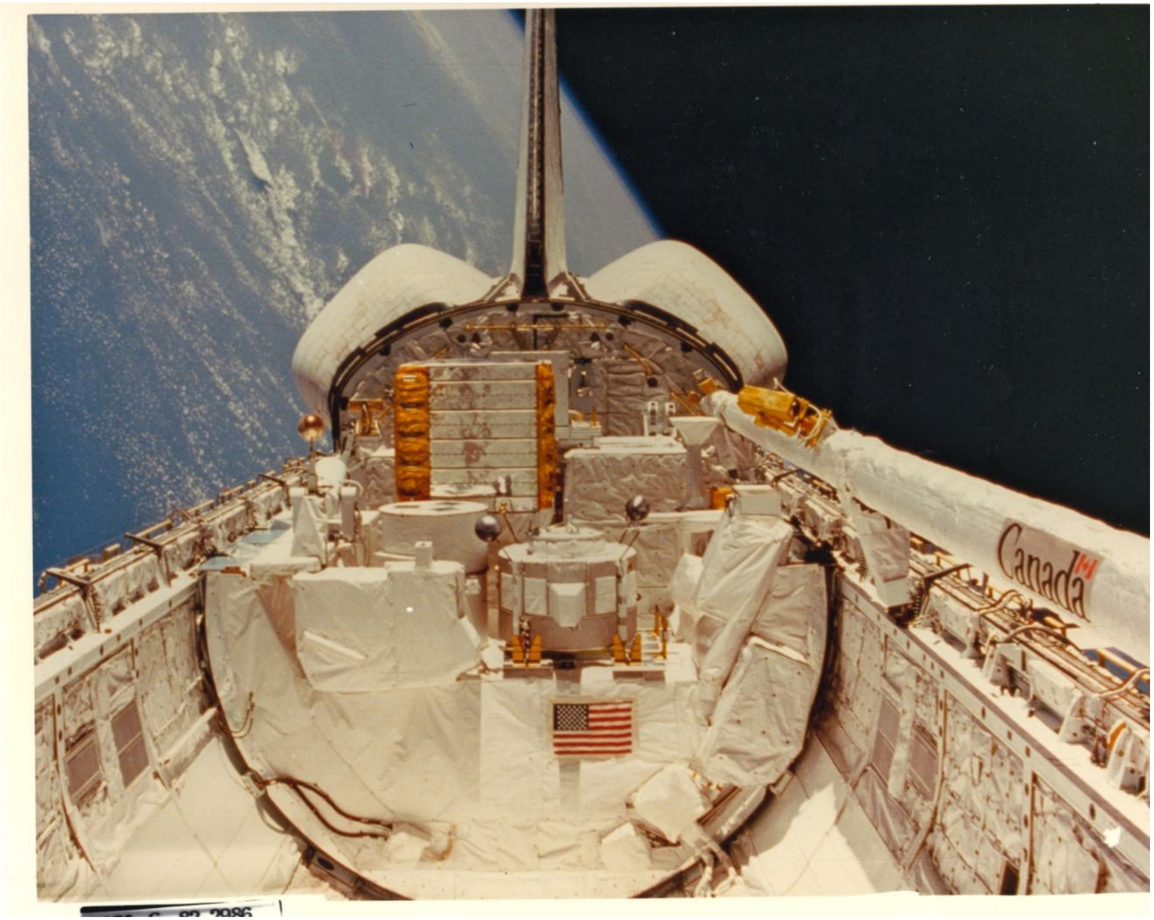
Samples located around the surface provided every angle of attack including the wake

LDEF



Delayed recovery made for more interesting results

STS-3



STS-3 Cargo Bay
GSFC Contamination Monitor Package (CMP)

STS-8

First time AO material erosion test vs time
Package design to STS-8 delivery was 56 days!

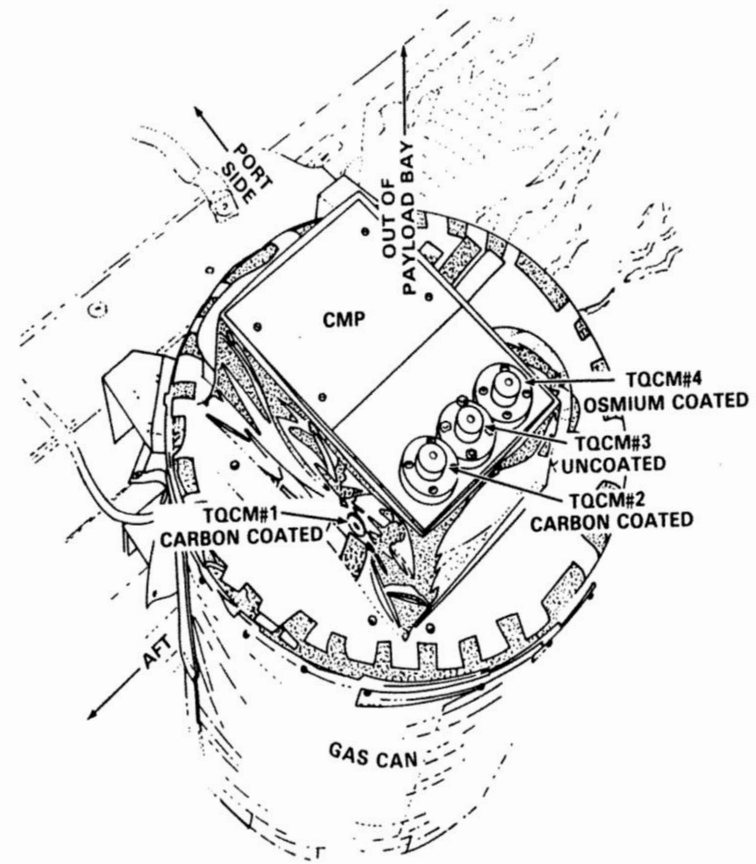
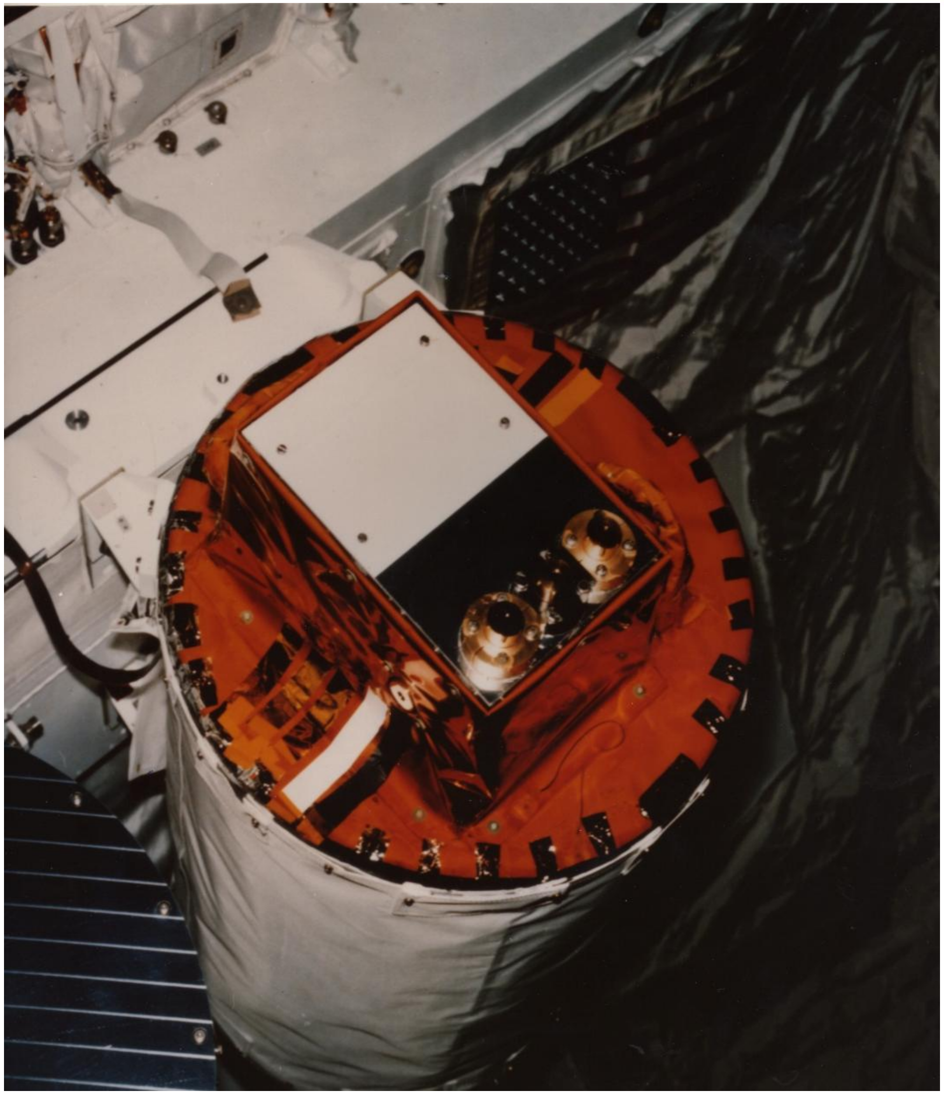


FIGURE 1
CMP CONFIGURATION, STS-8

STS-8

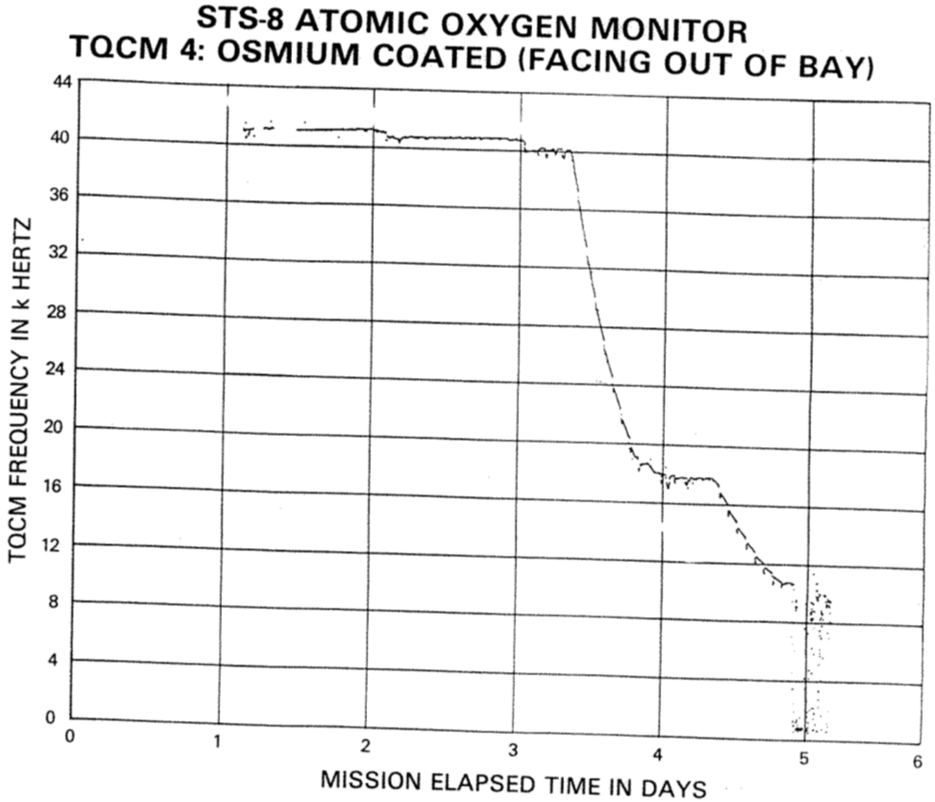
Pre-flight inspection

STS-8



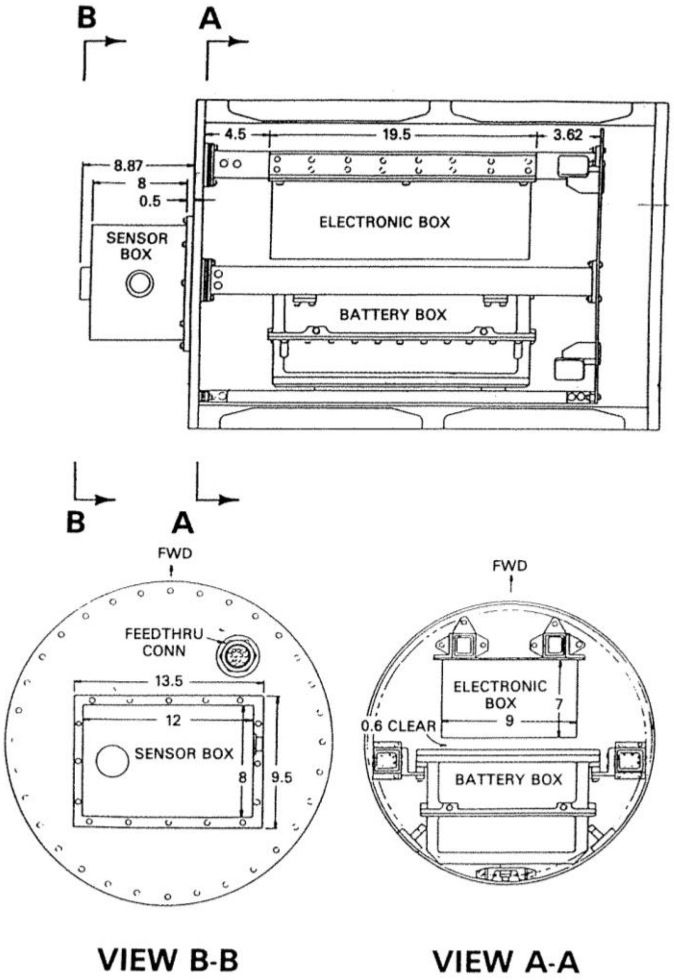
Post flight shows both eroded and non-eroded Kapton surfaces

STS-8



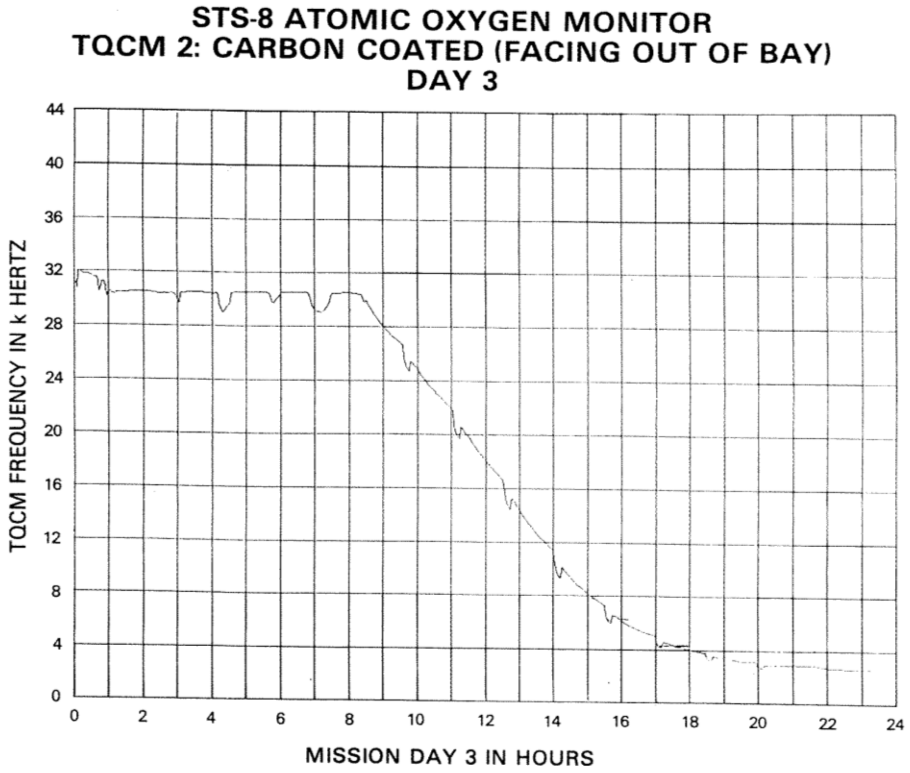
Can you guess STS-8 was bay-to-ram?

STS-8



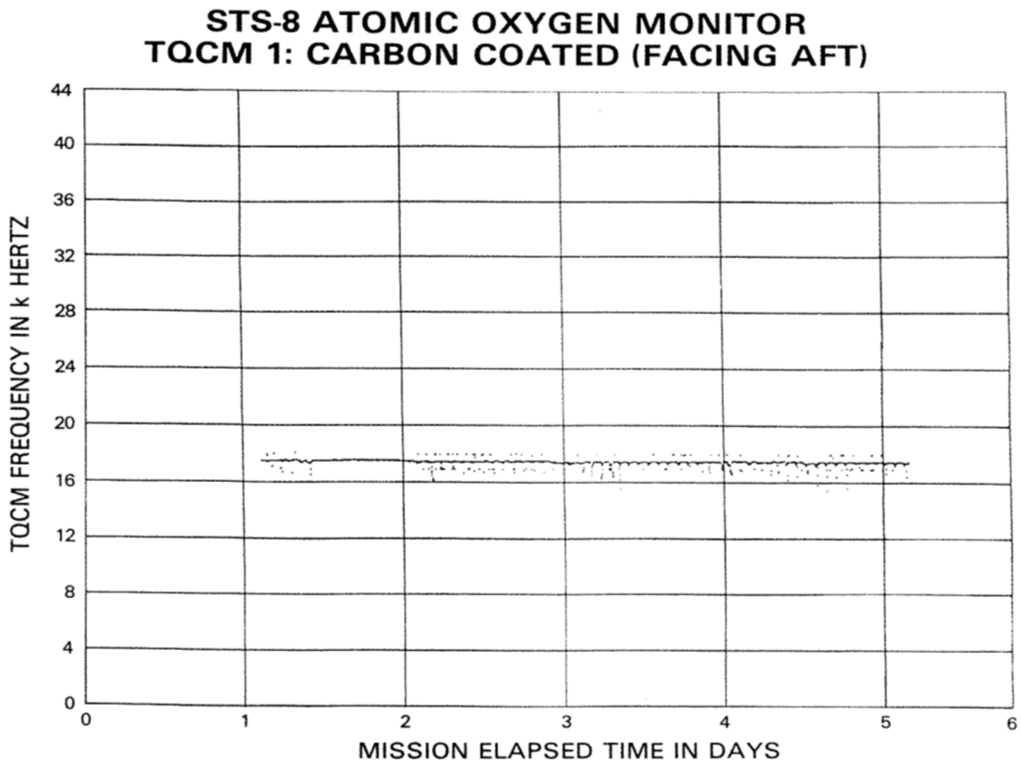
What is inside the GAS can?

STS-8



Notches in data are artifices of QCM solar effects

STS-8



QCM not in ram

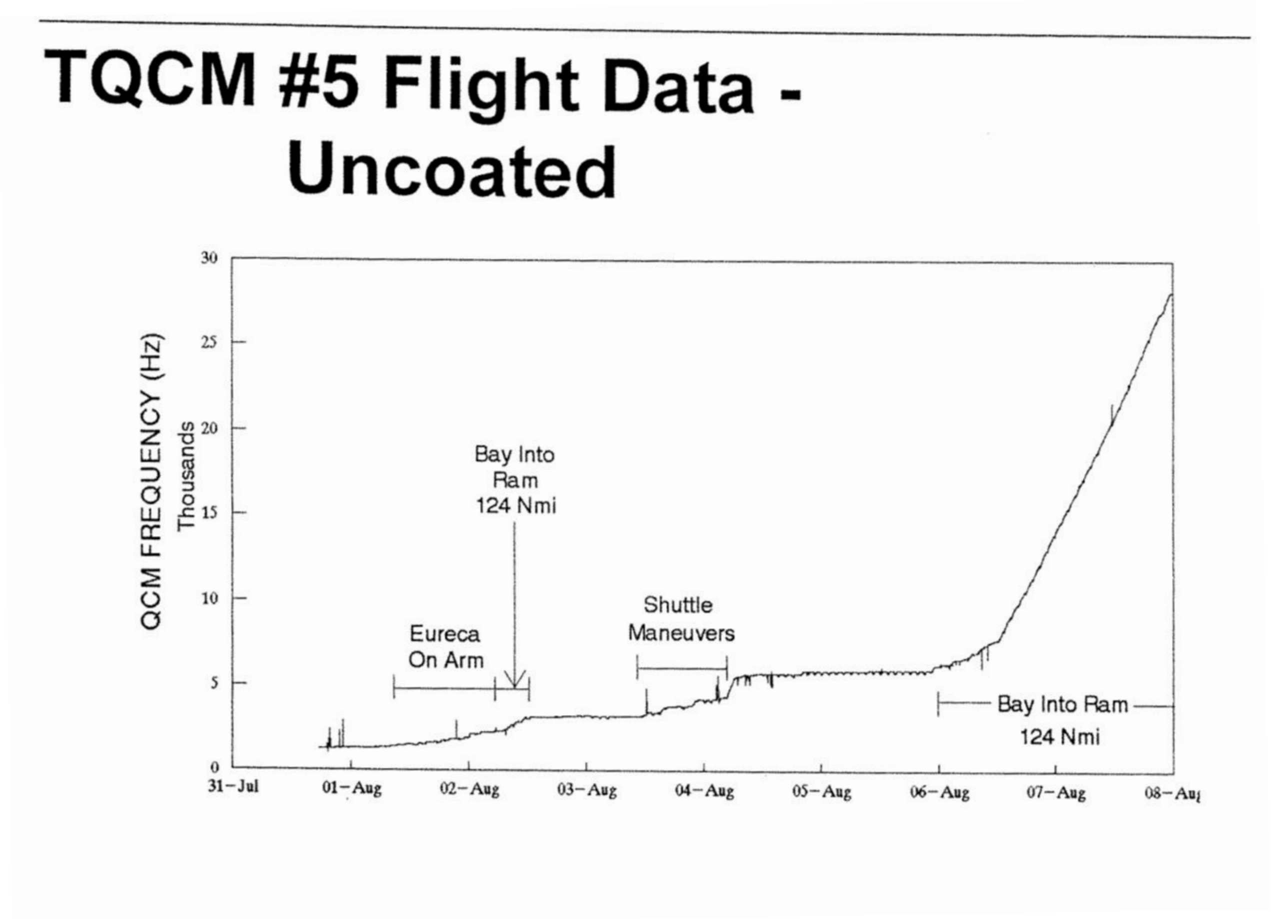
EIOM3/EMP

CONTAMINATION MONITORING PACKAGE

Quartz Crystal Microbalances

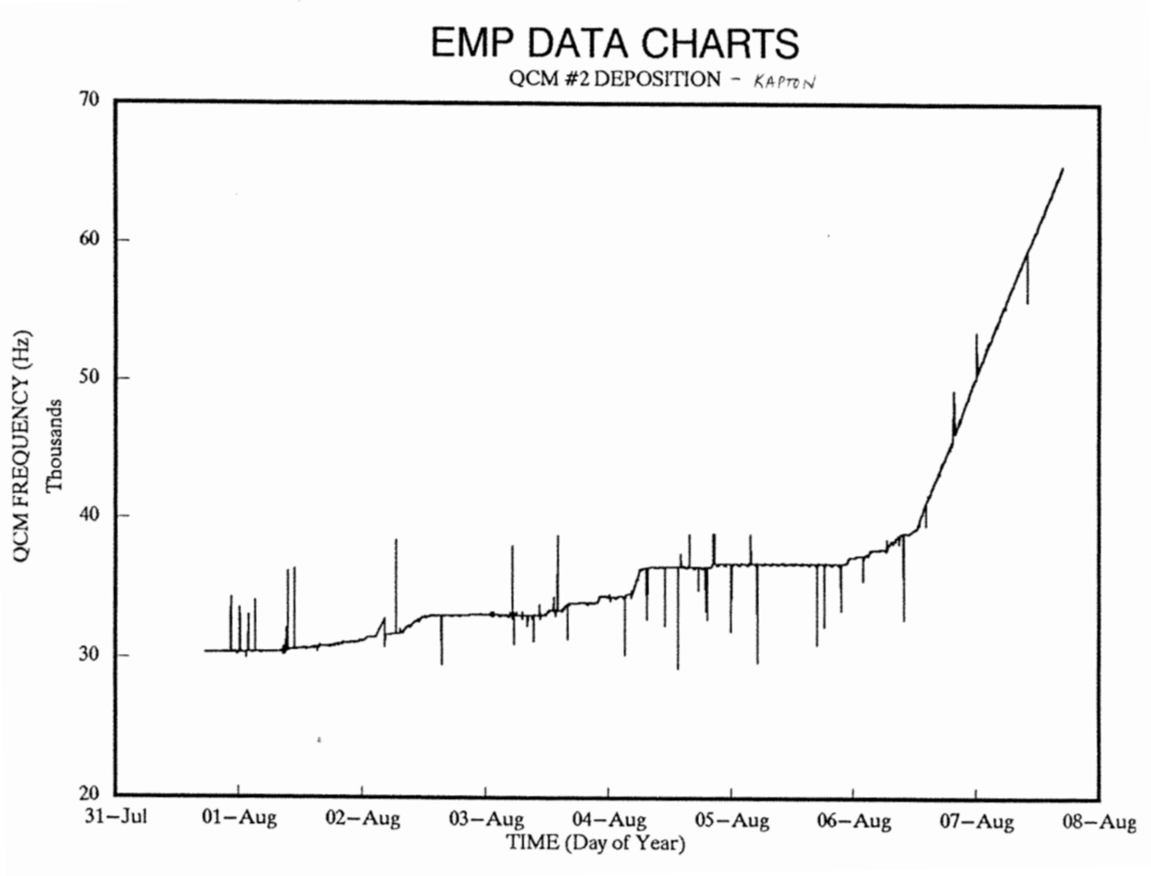
- 15 megahertz TQCM's manufactured by Faraday
- TQCM's were maintained at 30° throughout mission to prevent contaminant build-up on crystals.
- TQCM Coatings:
  1. Carbon
  2. Kapton
  3. Teflon
  4. Polyurethane
  5. Uncoated (control sample)

EIOM3 /EMP



QCM measures increased mass in ram

EOIM3/EMP Kapton coated QCM

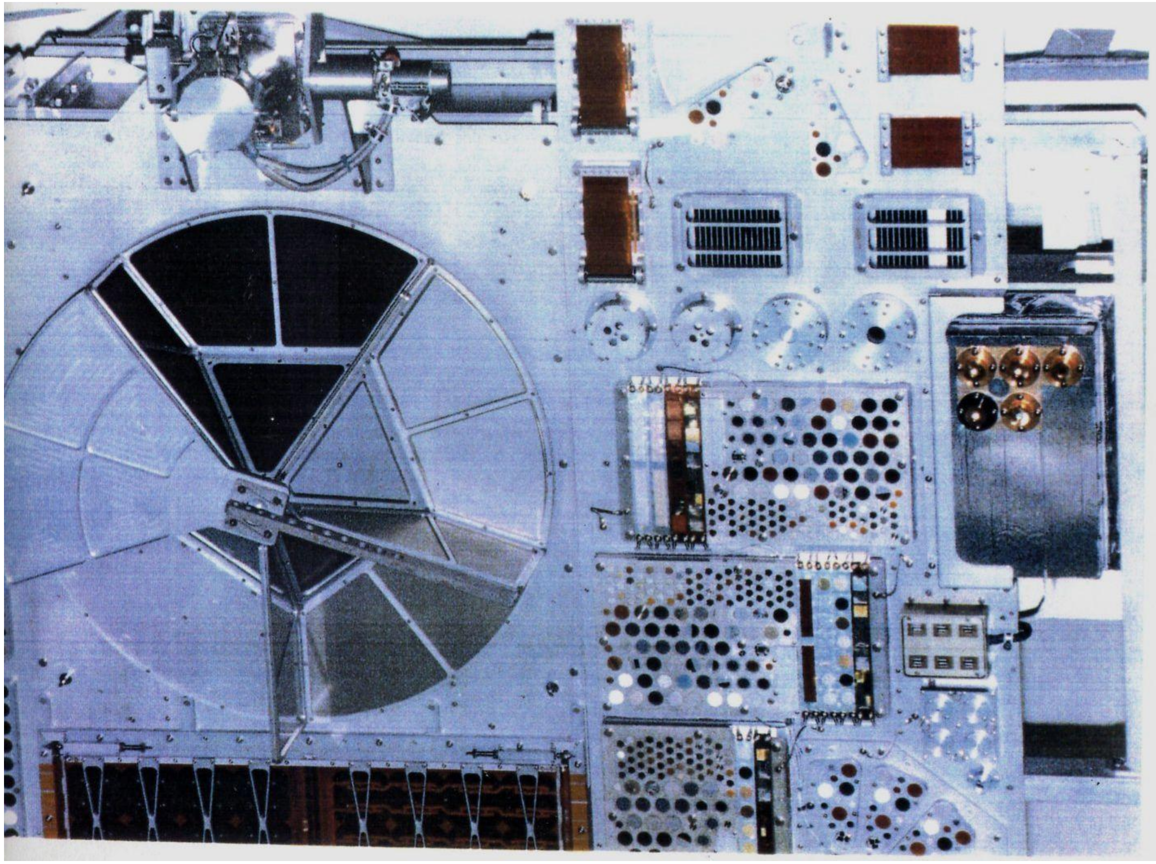


EMP PRELIMINARY RESULTS

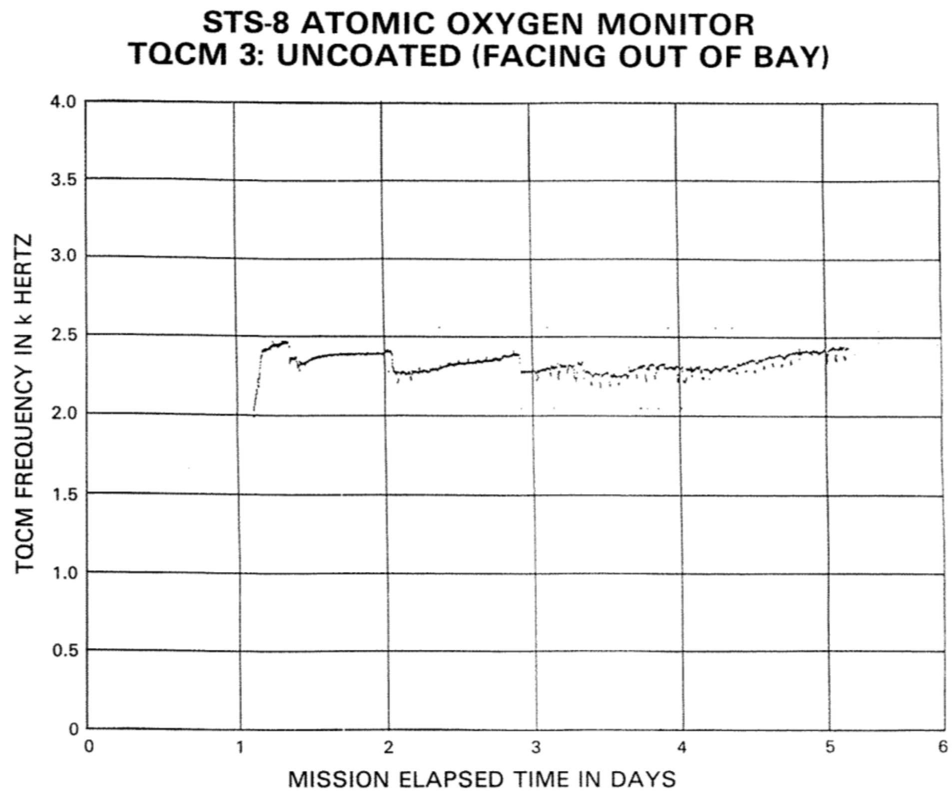
On-Orbit Results

- Results during mission showed a significant accumulation of contaminants on all the TQCM crystals instead of expected material erosion due to atomic oxygen.
- Greatest rate of accumulation observed with shuttle bay into the ram.
- Contaminant believed to be SiO_x originating from an unknown silicone source.
- Contaminant thickness of 4205 Angstroms accreted on the uncoated TQCM through out the mission.

IN-FLIGHT AO TESTING / EIOM-3



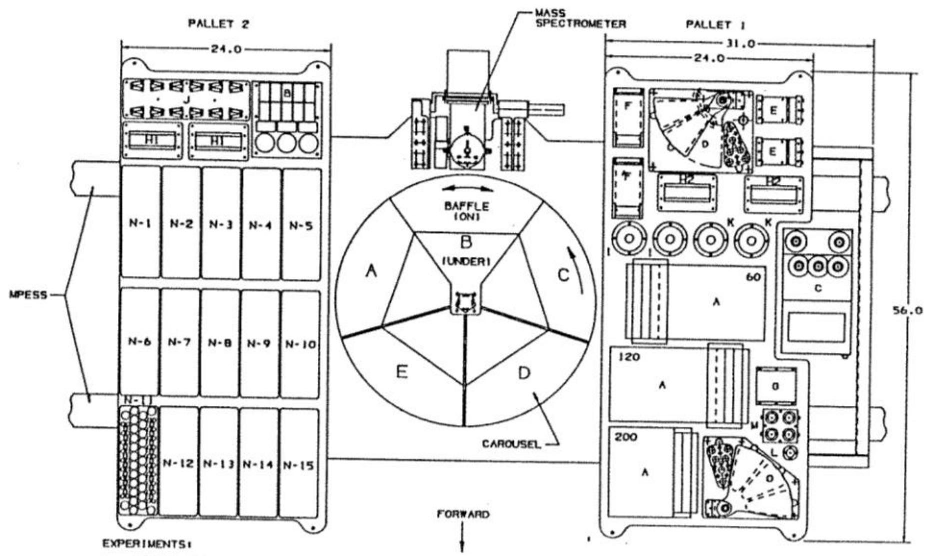
STS-8



Uncoated QCM used to detect contamination

STS-13

EOIM-3 EXPERIMENT PAYLOAD



EXPERIMENTS:

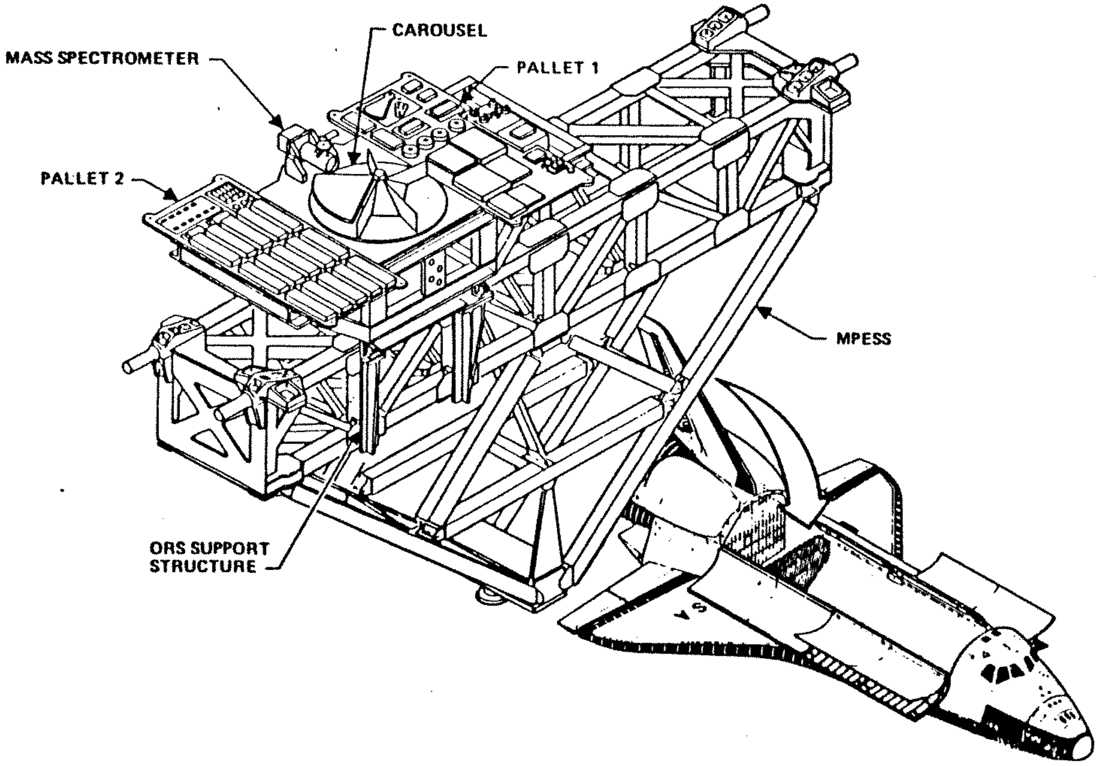
A - HEATED PLATE (JSC), 3 EA
B - ATOM SCATTERING EXPERIMENT (UAH), 1 EA
C - ENVIRONMENT MONITOR PACKAGE (GSFC), 1 EA
D - SOLAR UV EXPERIMENT (JSC), 1 EA
E - STATIC STRESS FIXTURE (MSFC), 2 EA
F - UNIFORM STRESS FIXTURE (MSFC), 2 EA
G - ATOMIC OXYGEN MONITOR (MSFC), 1 EA
H1 - COMPOSITE STRESS FIXTURE (LaRC), 2 EA
H2 - COMPOSITE STRESS FIXTURE (JSC), 2 EA
I - SCATTEROMETER (JPL), 2 EA
J - MECHANICAL STRESS FIXTURE (LaRC), 11 EA
K - REFLECTOMETER (LaRC), 2 EA
L - PIN-HOLE CAMERA (LaRC), 1 EA
M - SCATTEROMETER (AEROSPACE CORP.), 1 EA
N - SAMPLE CARRIERS, 15 EA
O - VARIABLE EXPOSURE TRAY, 1 EA

ENVIRONMENT MONITORING PACKAGE
STS-PAYLOAD CONTAMINATION TIM AUGUST 18, 1993 3

EMP provided real time data during flight

INFLIGHT AO TESTING STS-13

EOIM-3 EXPERIMENT PAYLOAD



EIOM 3 location in cargo bay

AO Erosion Yields for various materials

ATOMIC OXYGEN

MATERIAL	EROSION YIELD, 10EXP-24 CM3/ATOM
KAPTON H	3.0
CHEMGLAZE Z306	0.35
FEP TEFLON	0.037-0.50
CARBON	0.9-1.7
DIAMOND	0.021
OSMIUM	0.314
SILVER	10.5
TEDLAR (CLEAR)	3.2
TEDLAR (WHITE)	0.05-0.5
EPOXY	1.7
AL/SiO2	0.0
GOLD	0.0
AL	0.0

Loss of Thickness Calculation

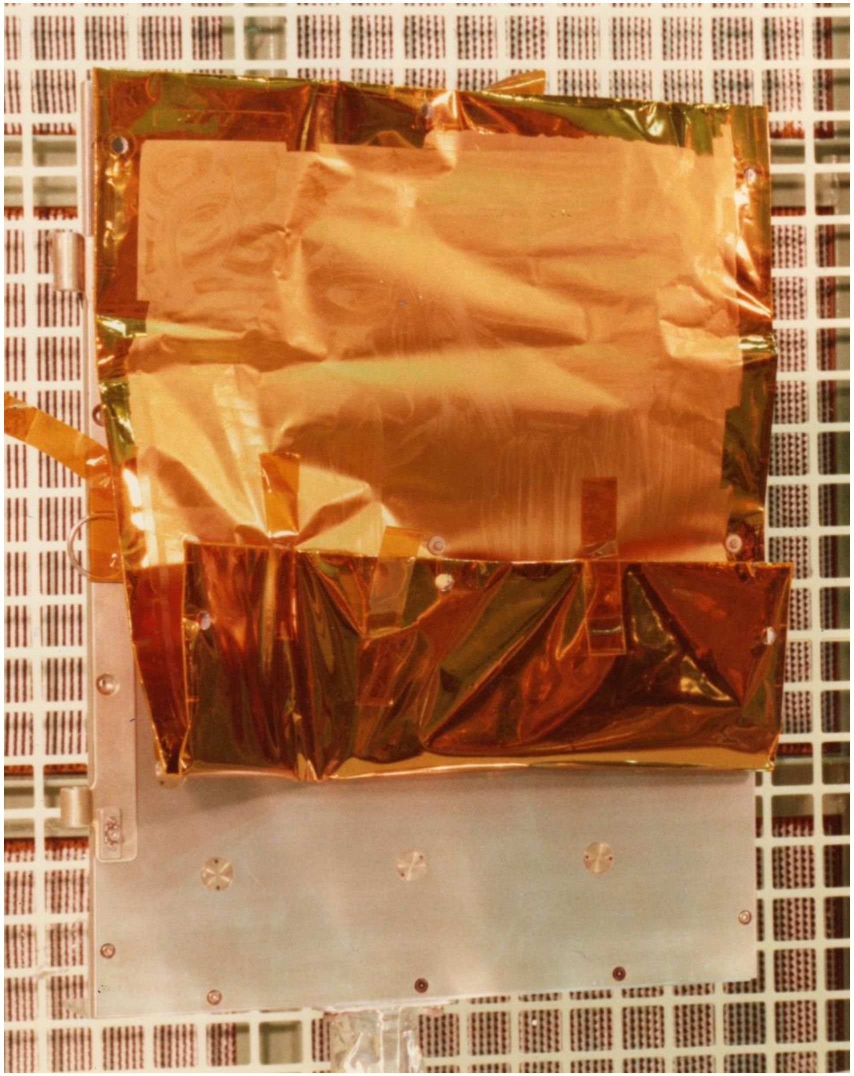
- Example: 400 km altitude, AO flux for solar max and min, Kapton surface in ram for 3 yrs

- Thickness loss/solar max
  = ($5x10^{14}$ atoms $cm^{-2}sec^{-1}$) x (3x365x24x3600 sec) x ($3.0x10^{-24}$ cm^3/atom)
  = 0.14 cm (55 mils)

- Thickness loss/solar min
  = ($2x10^{13}$ atoms cm-2sec^{-1}) x (3x365x24x3600 sec) x ($3.0x10^{-24}$ cm^3/atom)
  = 0.0057 cm (2.3 mils)

Returned Hardware

Solar Max S/C Blanket



First returned hardware from on orbit S/C.
Although looked contaminated, it tested very clean by surface analyses.

Hubble and Space Environmental Effects

(Material provided by Jackie Townsend)

Hubble Space Telescope
Experienced Space Environmental Effects

- The GSFC engineering team has an extensive hands-on experience in materials, coatings, contamination, and space environmental effects

HST
LDEF
Solar Max

- Slow crack growth in polymers was experienced at levels below accepted normal damage thresholds

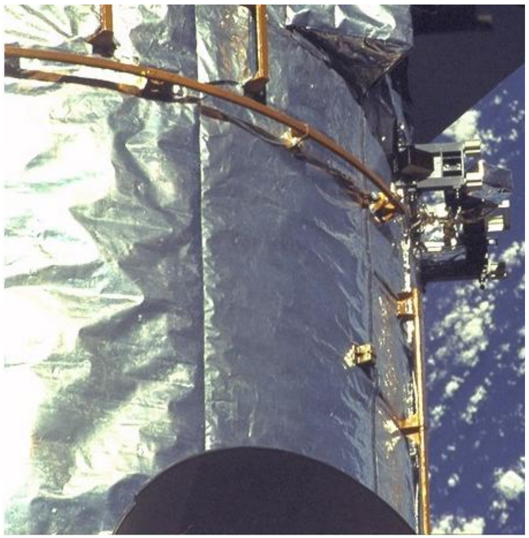
- Lesson learned from HST was that even when the environment is well defined, synergistic effects can still result in unforeseen degradation of materials

Solar Max Louver

Teflon tape came separated from substrate

Hubble's FEP Degradation Due to Space Environmental Effects

(Material provided by Jackie Townsend.)



HST SM1: 3.6 years in LEO

HST SM2: 6.8 years in LEO

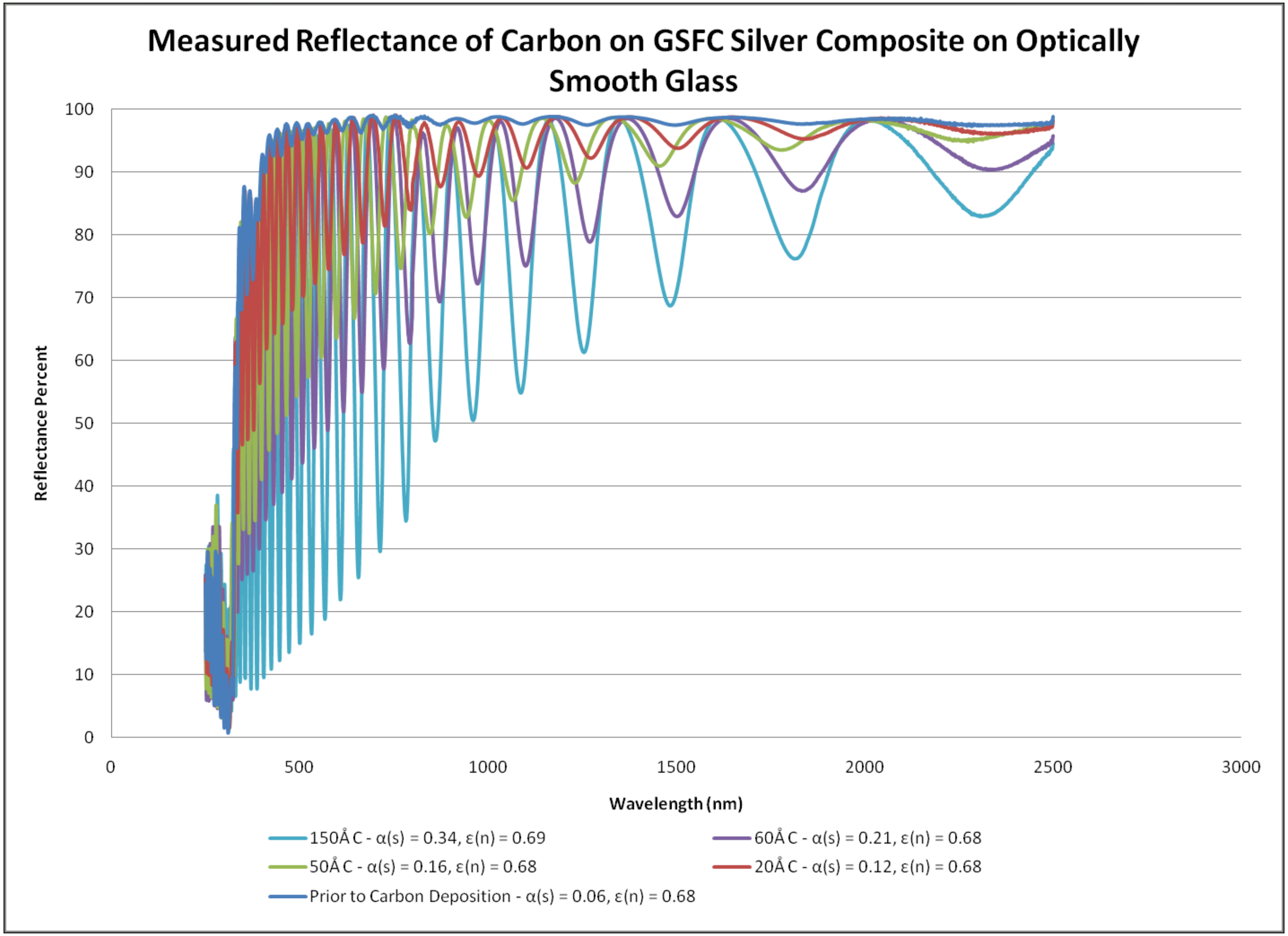
HST SM2: 6.8 years in LEO

- **HST at SM2 (6.8 years in LEO)**
  - 5-mil FEP Teflon with more than 100 cracks
- **Slow Crack Growth:** Synergistic effects of radiation (electron, proton, UV, VUV) and load (internal, blanket build and assembly, thermal cycling). Evaluated temperatures accelerates degradation.

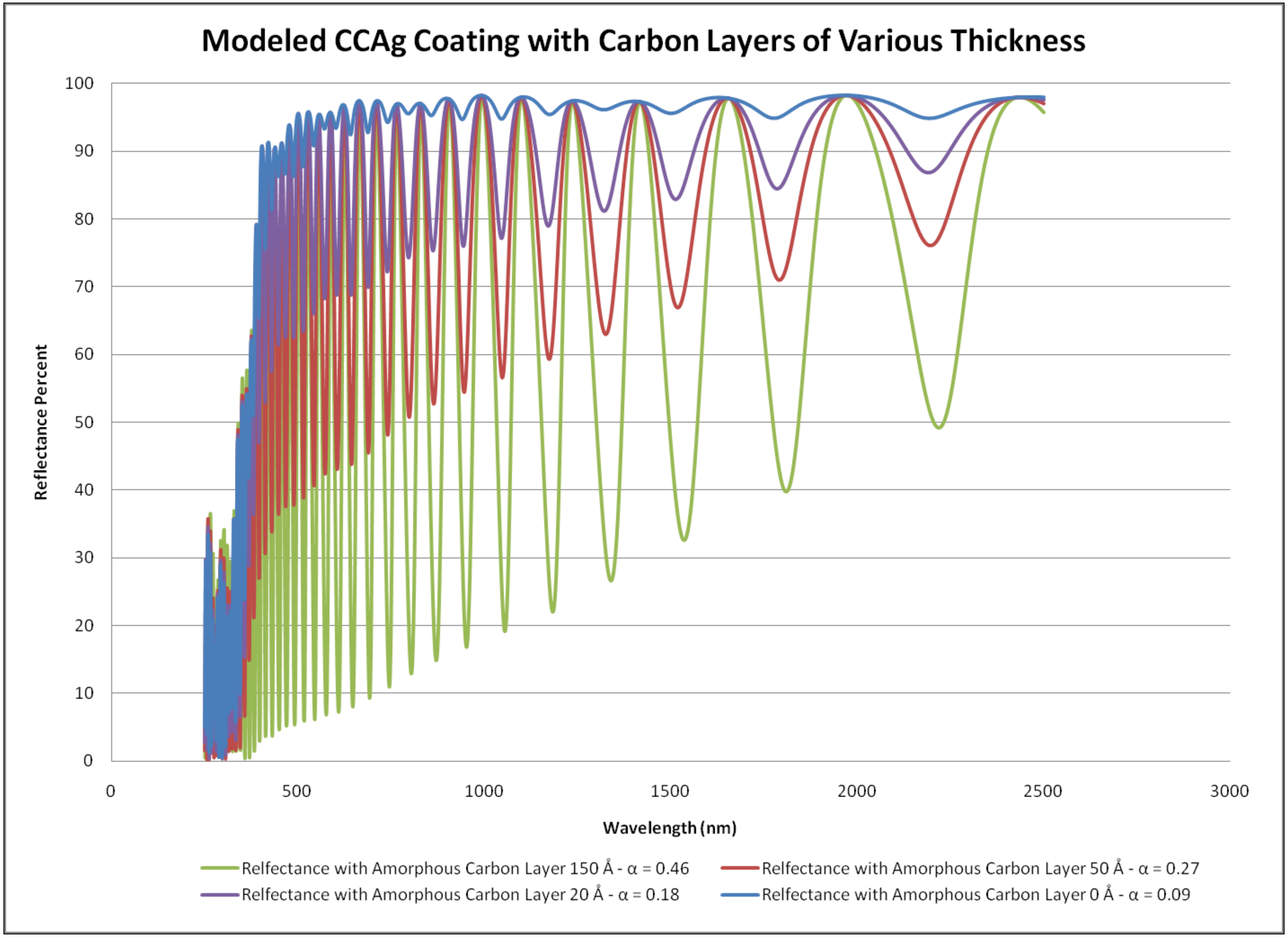
Contamination Effects

- How Does Contamination affect Coating Solar Absorptance?
  - Before on-orbit exposure? – Minor effects since hydrocarbons have low absorptance in the solar spectral region.
  - During on-orbit? – Hydrocarbons are fractured by UV and CP leaving only carbon films which adsorb heavily in the solar spectral region.
- Only carbon residues are seen on returned hardware. Silicones contaminates will also leave forms of SiO especially when AO is contained in the environment.

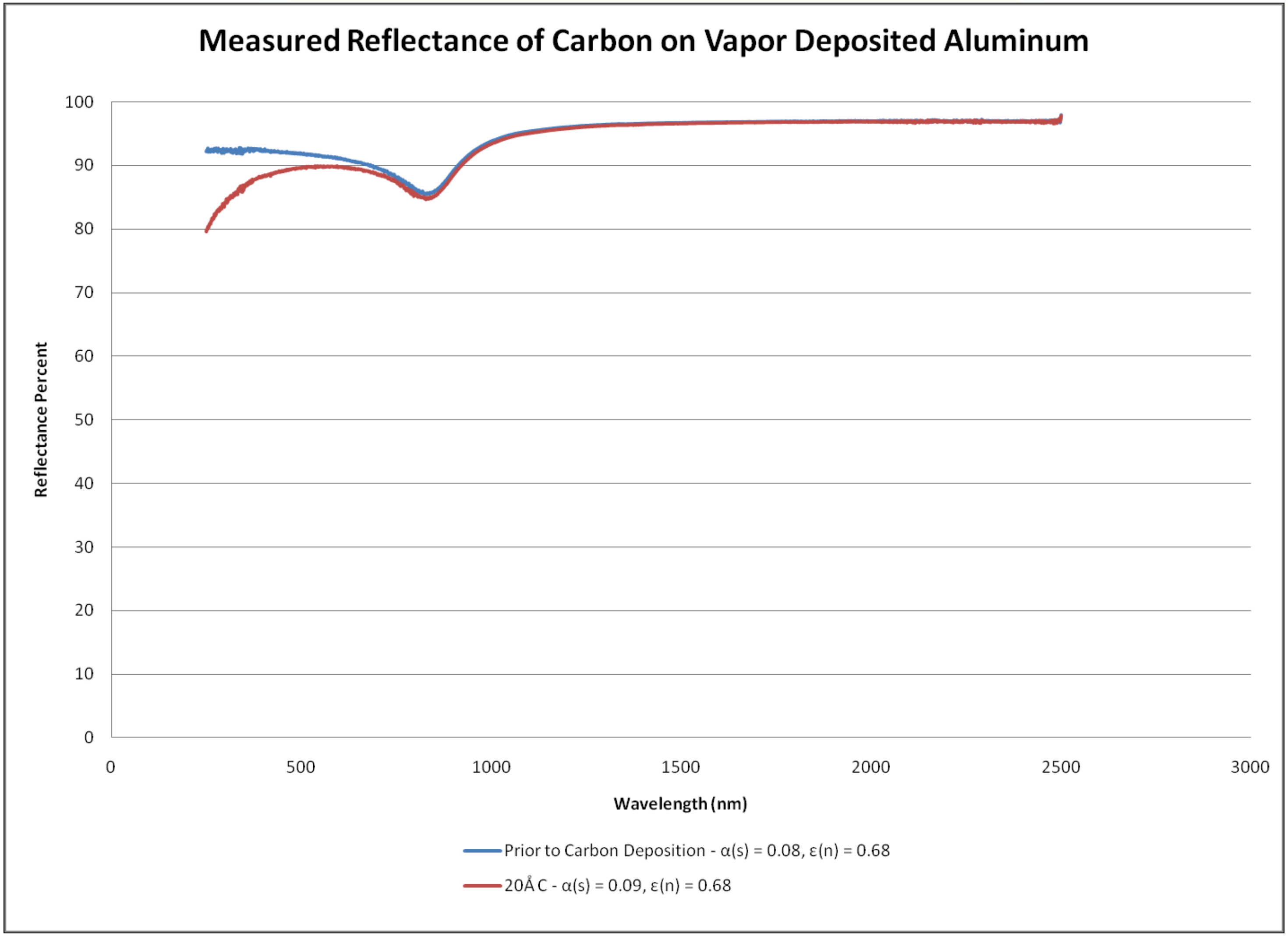
CARBON DEPOSITED ON CCAg MIRROR



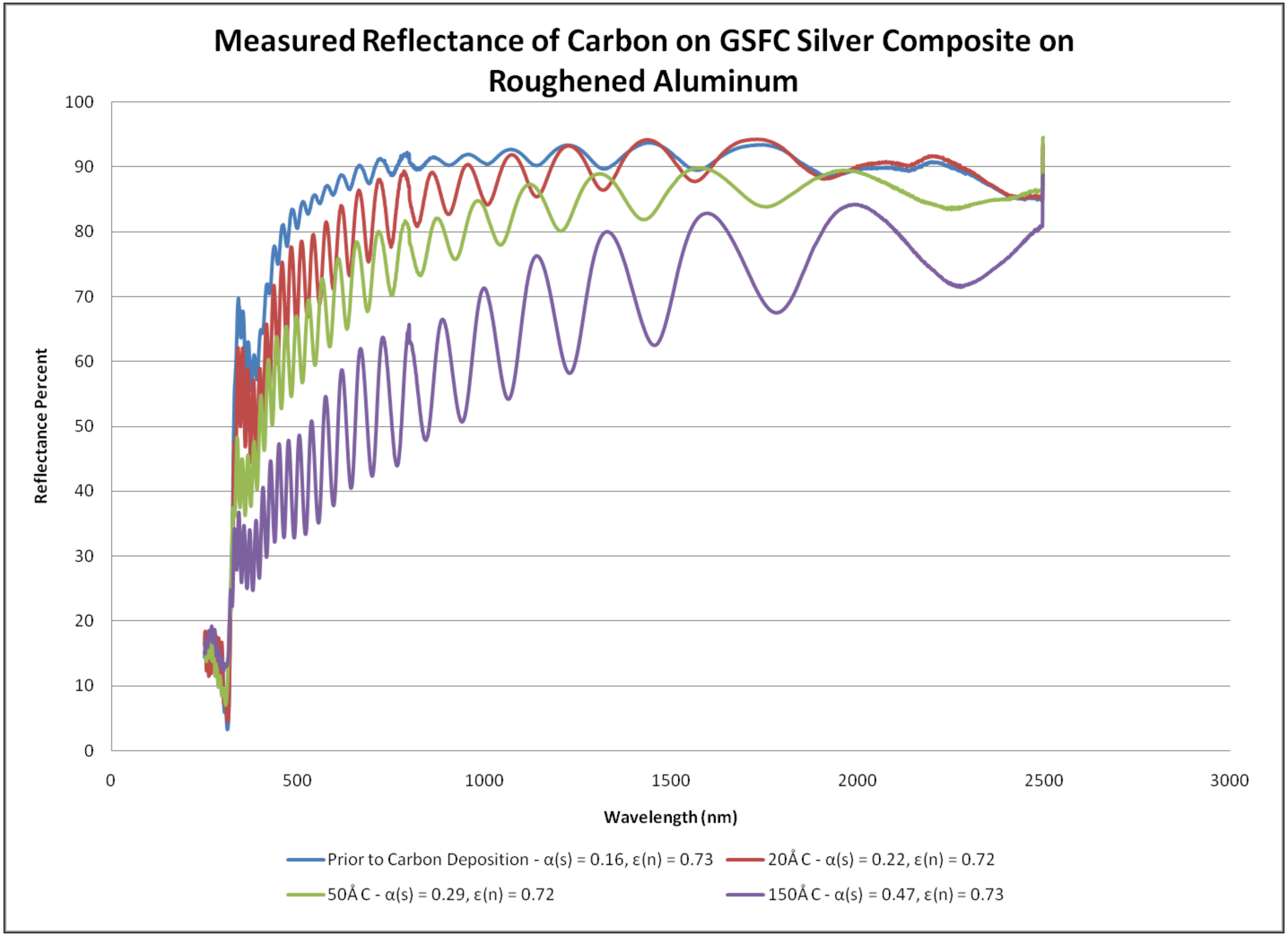
MODELED CARBON CONTAMINATION



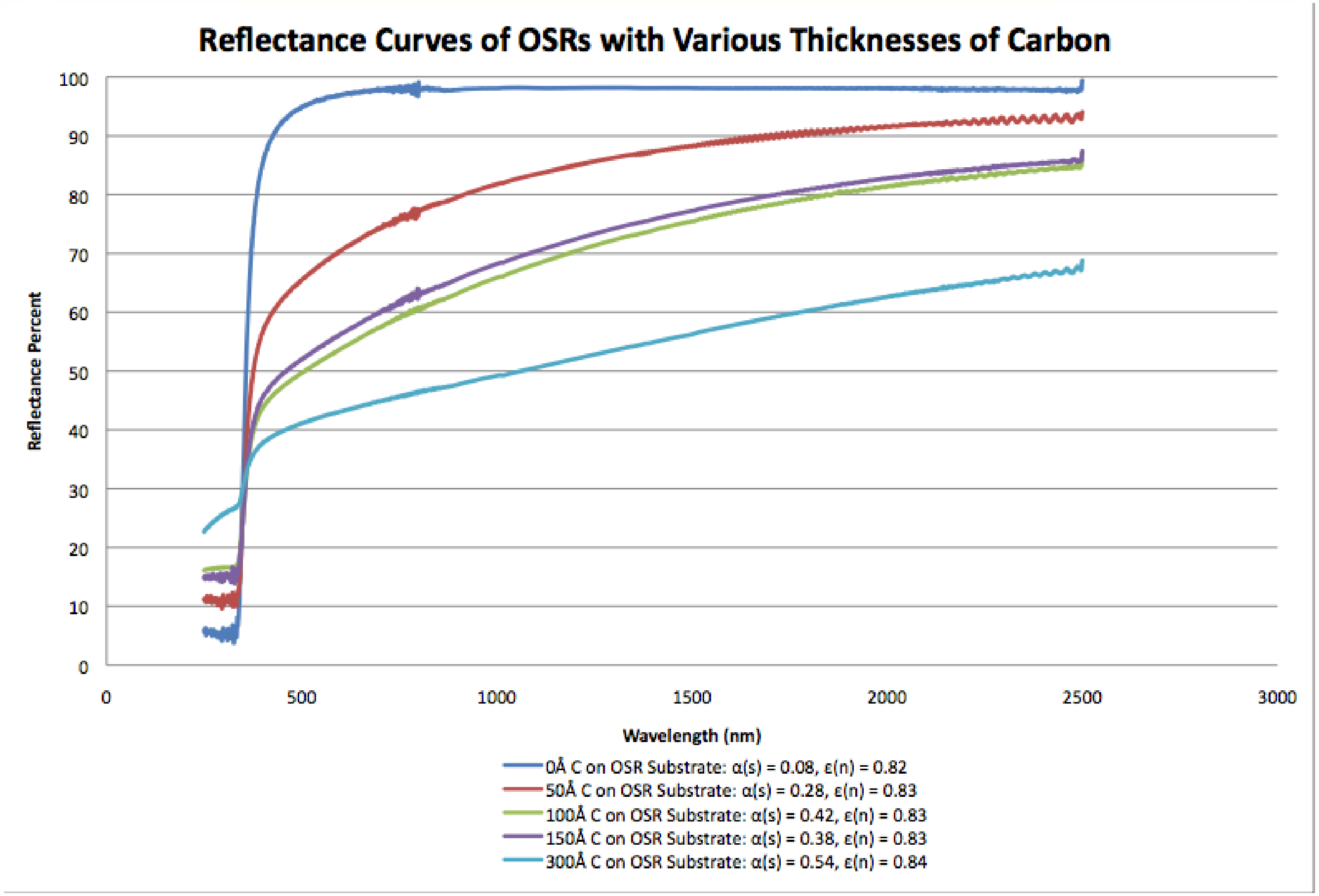
CARBON DEPOSITED ON ALUMINUM MIRROR



CARBON DEPOSITED ON CCAg ROUGHENED SURFACE

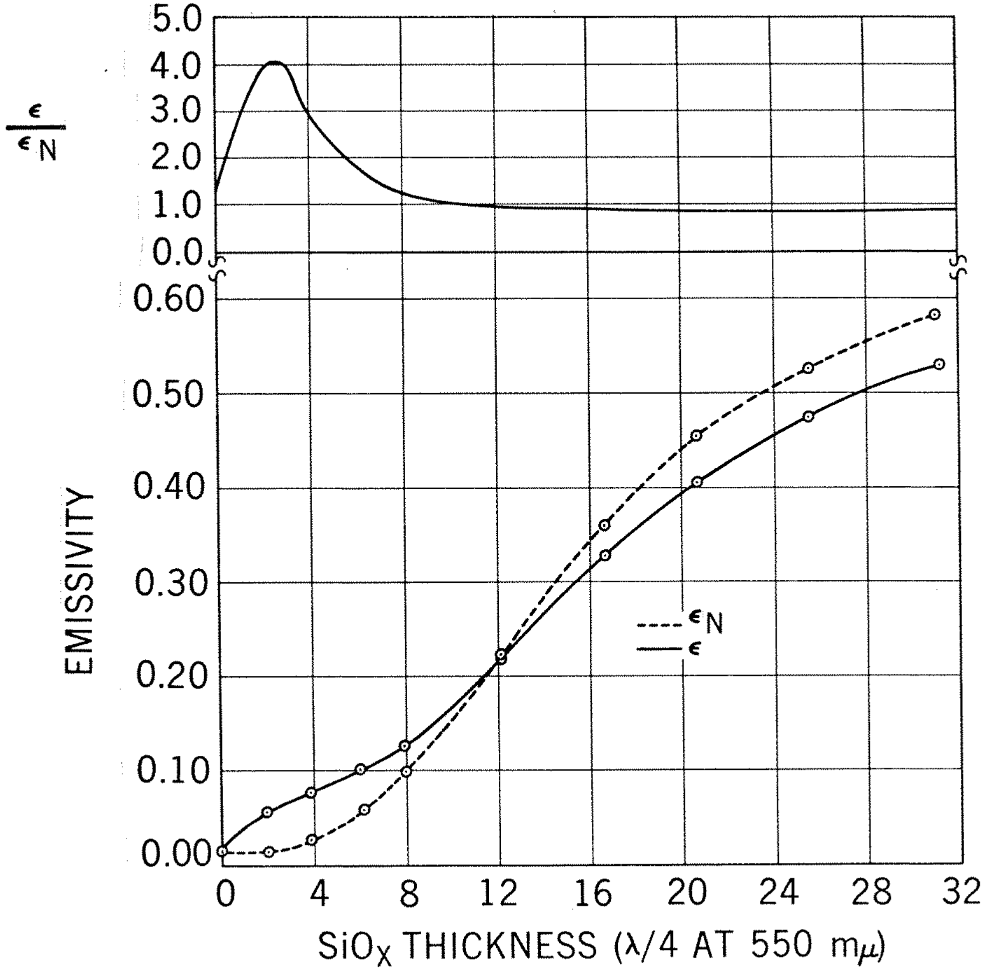


CARBON DEPOSITED ON OPTICAL SOLAR RELECTORS(OSR)



Delta absorptance same as contaminated CCAg

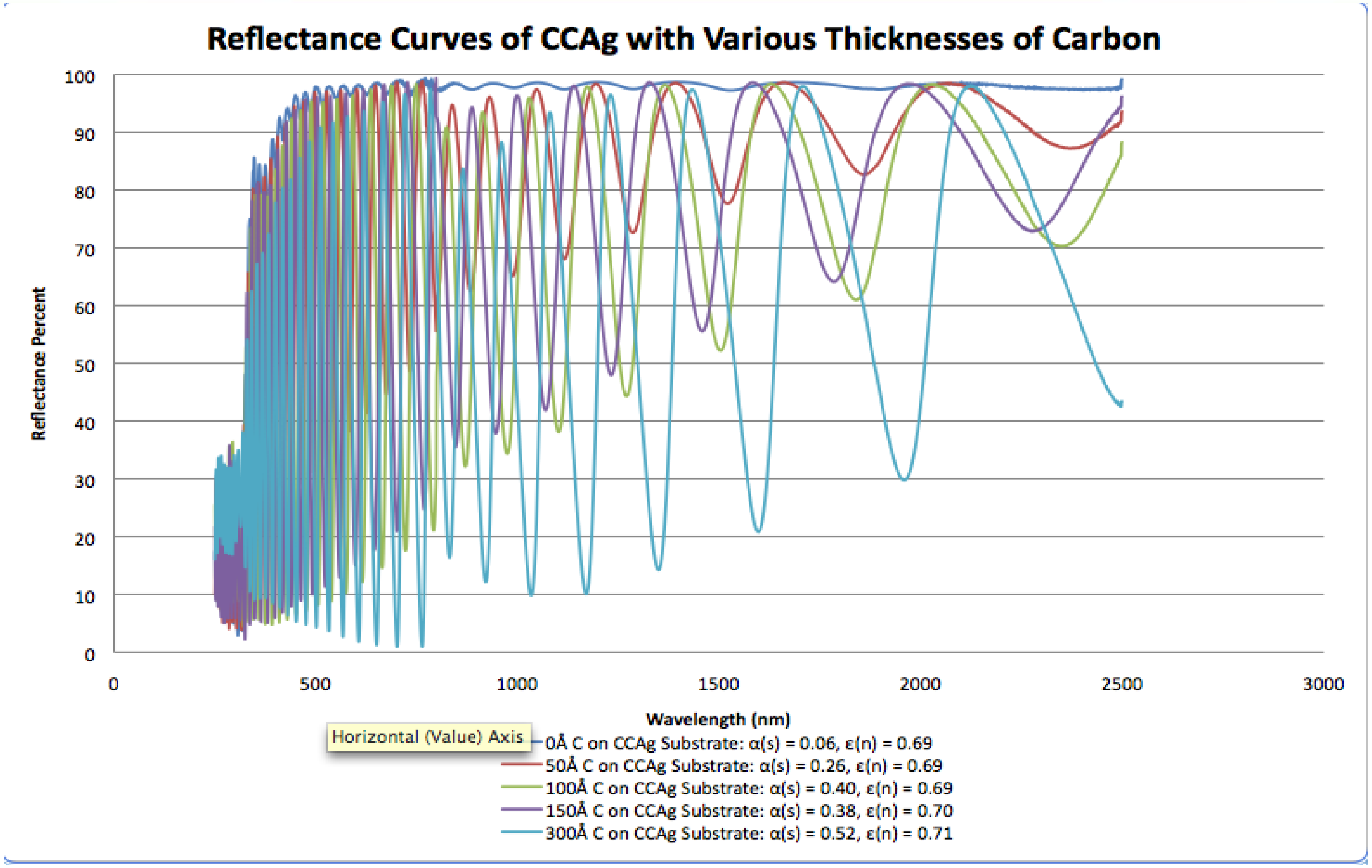
SiOx /Al Emittance vs Waveleng



Normal emittance(e_n) shows no change with deposit of the 1st quarterwave of SiOx.

Hemispherical emittance(e) shows a steady increase with SiOx deposition.

CARBON DEPOSITED ON CCAg MIRRORS



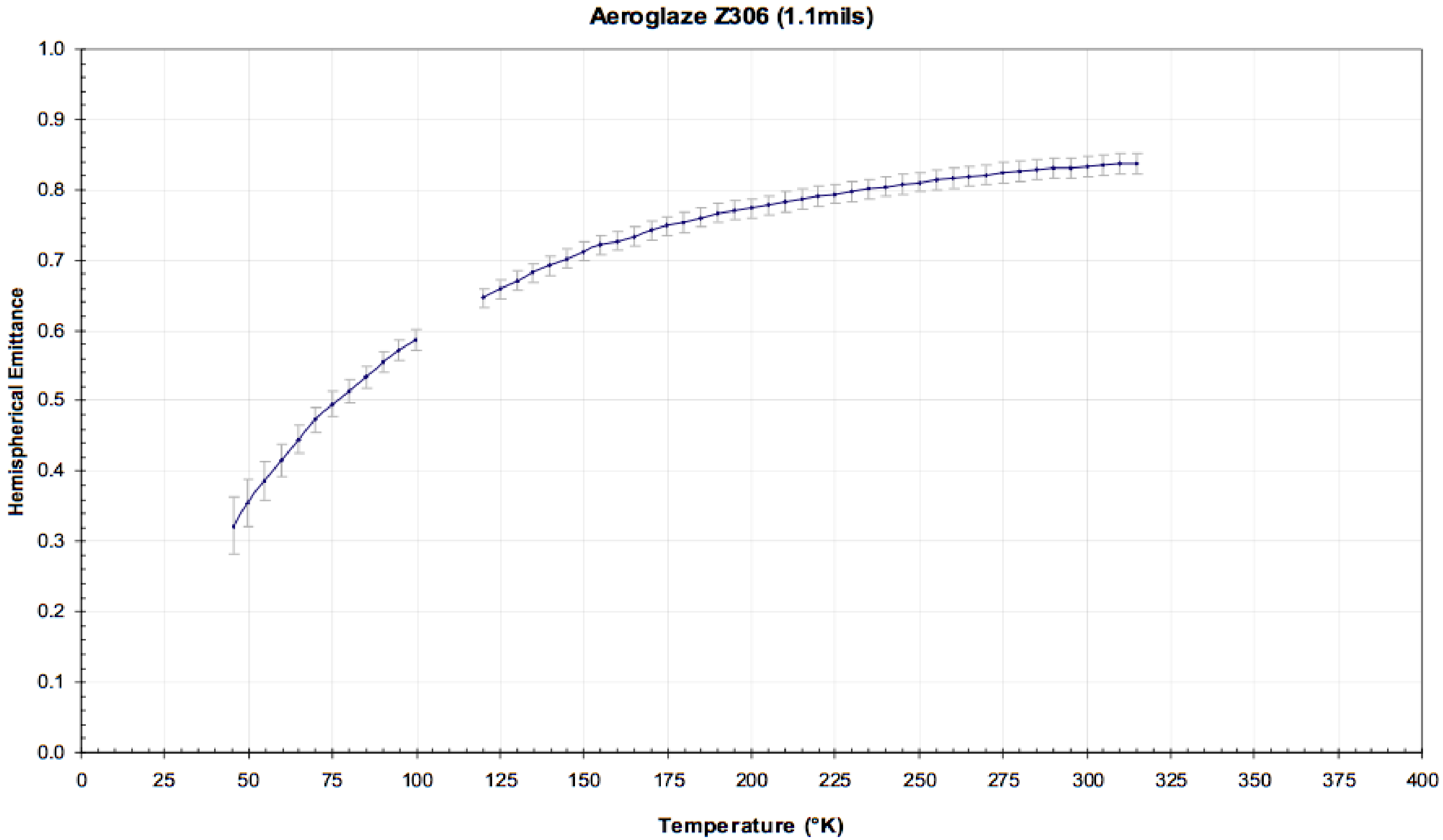
Compare delta absorptance with OSRs

Paint Thickness Issues

- White Paint Solar Absorptance versus Coating Thickness (versus adhesion)

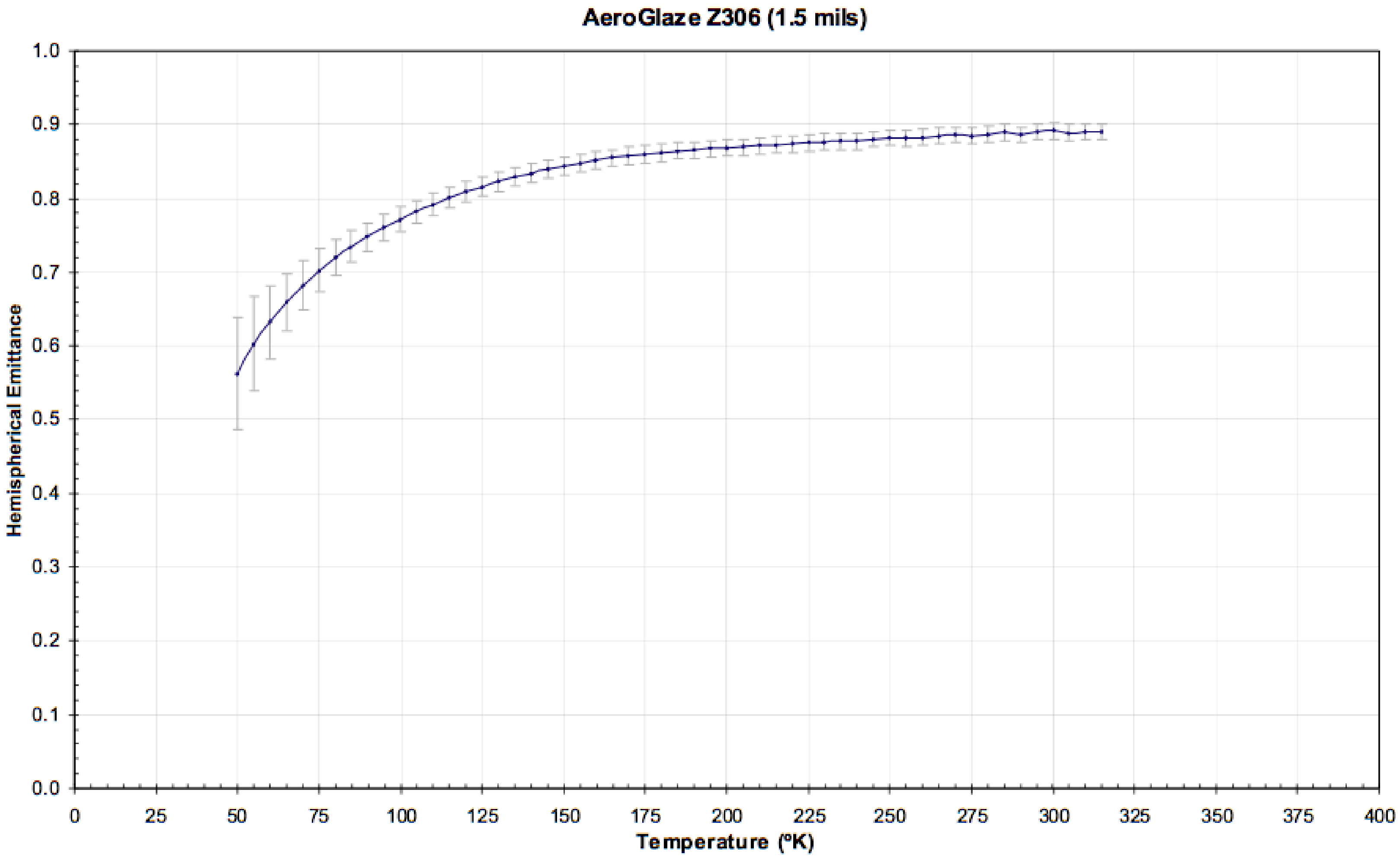
- Black Paint Low Temperature Emittance versus Thickness

Z306 (1.1 mils) HEMISPHERICAL EMITTANCE



Emittance at 300K is 0.84.
Emittance at 100K is 058.

Z306 (1.5 mils) HEMISPHERICAL EMITTANCE



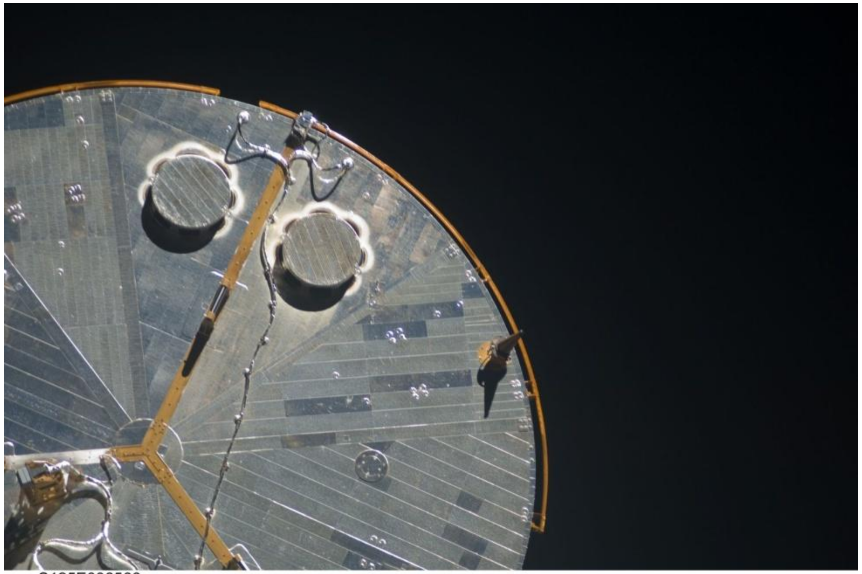
Teflon Adhesive Bleeding

- Silver cracking during application
- Adhesive UV Degrading
- Cures

Teflon Coated HST Aft Bulkhead

S125E006972

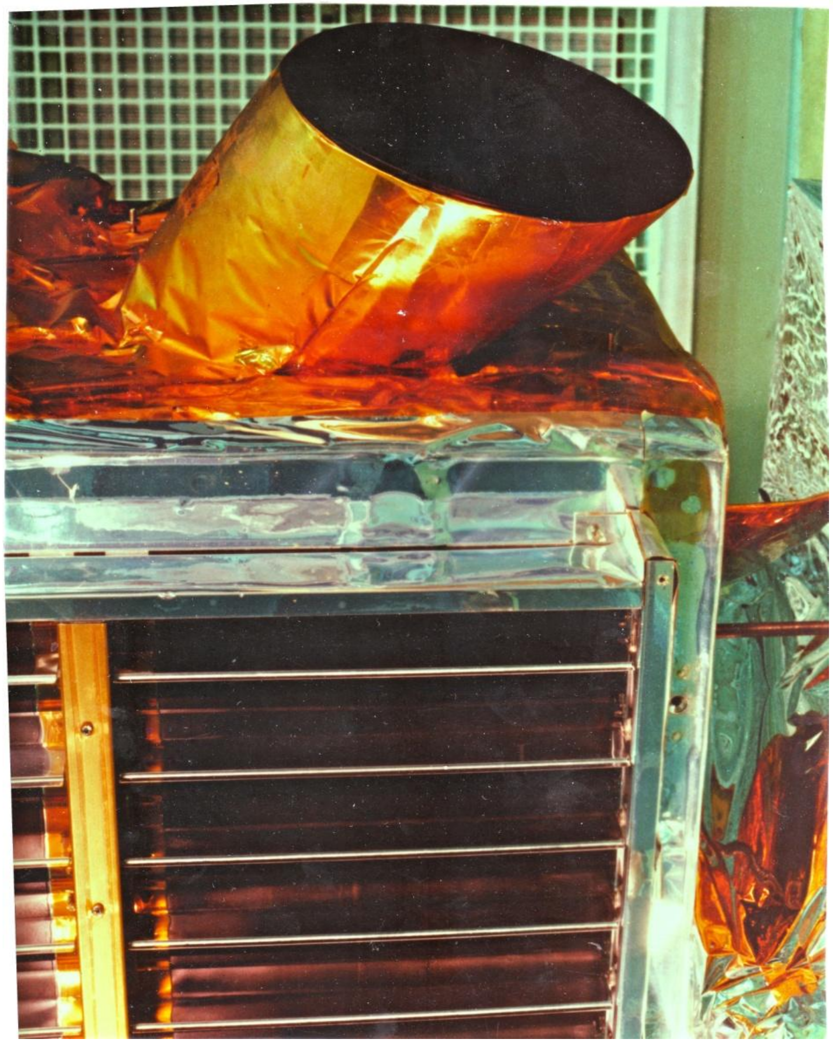
Note contamination darkening at vent covers



S125E006566

Adhesive bleeding and UV darkening

Solar Max Louver



Adhesive bleeding at the corner of the louver frame